High-Frequency Gain and Maximum Output Effects on Speech Recognition in Bone-Conduction Hearing Devices: Blinded Study

*Tyuana Sandim da Silveira Sassi, *Erika Cristina Bucuvic, *Eliane Aparecida Techi Castiquini, *Juliana Nogueira Chaves, †Marcia Kimura, ‡§Byanka Cagnacci Buzo, and *||Luiz Fernando Manzoni Lourençone

*Hospital for Rehabilitation of Craniofacial Anomalies (HRAC), Bauru; †Politec Saúde, Barueri, SP, Brazil; ‡Cochlear Latin-American, Panama Pacifico, Panama; §Santa Casa de Sao Paulo School of Medical Science, São Paulo; and ||Bauru School of Dentistry, University of São Paulo, Bauru, SP, Brazil

Introduction: Bone-conduction hearing device (BCHD) uses natural sound transmission through bone and soft tissue, directly to the cochlea, via an external processor that captures and processes sound, which is converted into mechanical vibrations. Key parameters, as maximum power output (MPO) and broader frequency range (FR), must be considered when indicating a BCHD because they can be decisive for speech recognition, especially under listening challenge conditions.
Objectives: Compare hearing performance and speech recognition in noise of two sound processors (SPs), with different features of MPO and FR, among BCHD users.
Materials and Methods: This single-blinded, comparative, observational study evaluated 21 individuals Baha 4 system users with conductive or mixed hearing impairment. The free-field audiometry and speech recognition results were blindly collected under the following conditions: unaided, with Baha 5, and with Baha 6 Max SP.
Results: In free-field audiometry, significant differences were observed between the SP at 0.25, 3, 4, 6, and 8 kHz, with Baha 6 Max outperforming Baha 5. The Baha 6 Max provided significantly better speech recognition than Baha 5 under all the speech in noise conditions evaluated. Separating the transcutaneous from the percutaneous users, Baha 6 Max Attract SP provided the best results and significantly lowered the free-field thresholds than Baha 5 Attract. The Baha 6 Max also significantly improved speech recognition in noise, among both Attract and Connect users.
Conclusion: The present study revealed that the greater MPO and broader FR of the Baha 6 Max device helped increase high-frequency gain and improved speech recognition in BCHD-experimented users.
Key Words: Bone conduction—Hearing loss—Speech audiometry.

Otol Neurotol **44:**1045–1051, 2023.

INTRODUCTION

Bone-conduction hearing devices (BCHDs) are hearing solutions that use natural sound transmission through bone and soft tissue, directly to the cochlea, via an external electronic device that captures, processes, and converts sound into mechanical vibrations. These vibrations, generated by external sound processors (SPs), are transmitted to an implant anchored to the skull and then conducted to the cochlea. Whether transcutaneous or percutaneous, such prostheses consist of a titanium device surgically placed in the mastoid bone, in addition to a skin-penetrating abutment (percutaneous) or a magnetic device (transcutaneous), to which the SP is attached (1). They provide effective hearing solutions for individuals with conductive and mixed hearing loss (HL), because they compensate for limitations in sound transmission associated with alterations or anomalies of the outer and/or middle ear (2–4). They are also indicated for individuals with profound unilateral sensorineural HL; however, in these individuals, the sound captured by the processor on the affected side will be transmitted directly to the contralateral cochlea (4–6).

BCHDs do not use air conduction and, as such, are not affected by air-bone gaps. Thus, BCHDs require less amplification than personal sound amplification products in individuals with conductive and/or mixed HL. For this reason, they provide better hearing results than air-conduction hearing aids for patients with an air-bone gap hearing level greater than 30 to 35 dB (7,8).

These types of prostheses have enabled individuals with the proper indications to reach an excellent hearing quality. However, the most common complaint, regardless of the

Address correspondence and reprint requests to Luiz Fernando Manzoni Lourençone, M.D., Rua Silvio Marchione 3-20, Vila Universitária, Bauru, SP 17012-900. Brazil; E-mail: luiz.fernando@usp.br
The authors report no funding sources.
B.C.B. is an employee at Cochlear LATAM. The remaining authors disclose no conflicts of interest.

DOI: 10.1097/MAO.0000000000004043

type of hearing aid, is the difficulty in following conversations in an acoustically unfavorable environment, that is, speech recognition in noisy situations. Therefore, understanding speech in the real world, permeated by competing noises, remains a considerable challenge for the population with HL.

A key factor to consider when selecting a BCHD for an individual is the gain that the device can provide, because the gain must be sufficient to amplify sounds above audiometric thresholds. Another crucial parameter for the selection process is the maximum power output (MPO), especially at a high frequency (9). MPO is defined as the strongest output level that a hearing device can provide and is an important parameter for selecting the best device for each patient. MPO is directly related to the amplification that the device can provide. For example, MPO can limit the gain available to the patient by making sounds inaudible, unpleasant, or even uncomfortable. Amplified speech signals must not reach MPO; that is, they should target the ideal gain in each frequency range (FR). Poor MPO and gain adjustment affects sound quality and, in turn, speech recognition.

Studies on gain and MPO effects on speech recognition performance with BCHDs remain scarce. In addition, most of previous studies suggest that increasing MPO and therefore gain improves speech recognition.

In 2021, the company *Cochlear* (Cochlear Ltd, Sydney, Austrália) launched the SP Baha 6 Max, which was designed to provide users with a higher gain and MPO than the previous model, thus promoting their speech recognition skills and therefore improving their quality of life. In this context, gain and MPO effects on speech recognition in noise must be assessed among experienced BCHD users.

Thus, the objective of the present study was to compare the hearing performance and speech recognition of two SPs with different FRs and MPOs in a group of experienced BCHD users. We hypothesized that the SP with a wider FR and a higher MPO would improve speech recognition by better providing users with high-frequency cues for speech recognition in noisy environments.

MATERIALS AND METHODS

Study Center and Population

This single-blinded, comparative, retrospective, observational study was approved by the Ethics Committee under opinion number 5.265.370. The research was conducted in accordance with the precepts of Resolution 466/2012 of the Brazilian National Health Council (*Conselho Nacional de Saúde*) and with good practices in scientific research, as defined by International Organization for Standardization 14155 and by the 2020 International Council for Harmonization of Technical Requirements for Pharmaceuticals for Human Use guideline on Clinical Safety Data Management: Definitions and Standards for Expedited Reporting (2020 ICH-E2).

The research center was a tertiary referral hospital, where the study population received the implants free of charge from the Brazilian government. SP updates were also provided by public policies for hearing care in Brazil. Thus, the data were collected through a documentary analysis of medical records of patients monitored at the study center with unilateral Baha BCHD implants and a Baha 4 Attract or Connect SP.

All individuals invited to participate in this research and their legal representatives agreed to participate in the study and signed the Informed Consent Form and the Informed Assent Form, when younger than 18 years.

The following eligibility criteria were applied: individuals with a unilateral BCHD Baha implant, native Brazilian Portuguese speakers, both male and female, older than 12 years, had been using the Baha 4 processor for more than 2 years, and were undergoing a process for updating their Baha 4 SP because they had broken or lost the device. The exclusion criteria were patients with cognitive and/or neurological disorders who were unable to complete the research procedures.

Because of public health policies, all new SPs would be provided free of charge and would be the Baha 6 Max model. Because the hospital is a research center, when the government approved the updates, a study protocol was designed to assess whether the acoustic characteristics of the device, the Baha 6 Max, were superior to those of its previous version, the Baha 5 device. Thus, data were blindly collected from the patients, and the same procedures were performed with both devices: Baha 6 Max and Baha 5.

Hearing Aids

All study procedures were performed with both hearing aids: Baha 5 and Baha 6 Max. A single-blinded study was performed because the two SPs were physically similar (Fig. 1), and the participants were all previous Baha 4 users who were in the process of being upgraded to a new model. The main difference between the SPs is that the Baha 6 Max system had an actuator and a more recent signal processing system than the Baha 5, resulting in a higher MPO and higher high-frequency gain, according to the manufacturer.

At the end of data collection, the SPs of all participants were updated to the Baha 6 Max model. Moreover, only the evaluators knew which processor was tested in each condition.

Procedures

All tests were performed with both SPs, the Baha 5 and the Baha 6 Max. The SPs were individually fitted to the participants, according to the manufacturer's instructions, using the Cochlear fitting software BAHA v4.45 and bone-conduction threshold measurements, a directionally disabled microphone, automatic sound classification, position compensation, and noise reduction.

Free-field pure-tone thresholds at frequencies that ranged from 0.25 to 8 kHz were assessed under three conditions, namely, unaided, with Baha 5, and with Baha 6 Max, using the warble tone as a modulated stimulus in an Astera 2 Madsen clinical audiometer (Otometrics A/S, Taastrup, Denmark). The loudspeaker was positioned at 0-degree azimuth, 1 m from the individual, in a sound booth.

FIG. 1. Baha 5 and Baha 6 Max SP. SP indicates sound processor.

Speech recognition was assessed using the hearing in noise test (HINT) (10), which was performed in an Astera 2 Madsen clinical audiometer (Otometrics A/S), with loudspeakers positioned at 0- and 180-degree azimuth, 1 m from the individual, in a sound booth. The test was performed under fixed and adaptive noise, always presented speech at 0-degree azimuth, and varied the position of the noise between 0 and 180-degree azimuth. For the fixed-noise condition, the noise was positioned at 180-degree azimuth, the speech level was always maintained at 65 dB SPL, and the signal-to-noise ratio was maintained at 0 dB. For the adaptive-noise conditions, the noise was always maintained at 65 dB SPL, and the speech varied with the participants' correct answers.

The SPs were tested in a random order. Once a processor was programmed, all measurements with that processor were performed. After completing the tests with the first processor, the participant rested for a while and subsequently signaled to proceed. Then, the second processor was then programmed, and the corresponding measurements were performed. At the end of the two evaluations, the users were asked which devices they liked best (the first or second device tested) and the factors that led to their choice.

Data Analysis

The results from free-field pure-tone audiometry test were analyzed using the Friedman test to compare three situations, unaided, with Baha 5 SP, and with Baha 6 Max SP, followed by the Wilcoxon signed rank test. The HINT results of the Baha 5 and Baha 6 Max SP were analyzed using the Wilcoxon signed rank test. The free-field pure-tone audiometry and HINT results with the Baha 5 and Baha 6 Max were also compared, by prothesis (Baha Attract and Baha Connect), using the Wilcoxon signed rank test.

RESULTS

Considering the aforementioned criteria, the medical records of 21 individual Baha 4 users, 8 male and 13 female individuals, with a mean age of 21.5 years (minimum of 14 yr and maximum of 43 y), were selected and analyzed. The characteristics of the study cohort are presented in Table 1.

Figure 2 shows the mean free-field pure-tone thresholds of the 21 individuals, at frequencies ranging from 0.25 to 8 kHz, under three conditions: unaided, with the Baha 5 SP, and with the Baha 6 Max SP. All audiometric thresholds assessed with Baha 5 and Baha 6 Max were significantly better than those assessed without any device ($p < 0.05$).

TABLE 1. *Study population*

	Sex	Age, yr	Etiology	PTA BC, dB (0.5, 1, 2, and 4 kHz)	Degree of Hearing Loss	Implanted Ear	BCHD
1	F	28	malf	15	Profound	R	Connect
2	F	21	malf	11.25	Moderate	R	Connect
3	M	14	malf	10	Severe	R	Attract
4	M	23	malf	3.75	Severe	L	Attract
5	M	15	malf	6.25	Severe	L	Attract
6	M	23	malf	7.5	Severe	L	Connect
7	F	19	malf	2.5	Moderate	R	Attract
8	F	23	malf	8.75	Severe	L	Connect
9	F	15	malf	5	Moderate	R	Attract
10	F	43	COM	28.75	Profound	R	Connect
11	F	25	malf	7.5	Severe	R	Connect
12	M	14	malf	6.25	Moderate	L	Attract
13	F	18	malf	3.75	Severe	L	Attract
14	M	34	malf	15	Severe	R	Connect
15	F	22	malf	23.75	Severe	L	Connect
16	F	17	malf	7.5	Moderate	R	Connect
17	M	16	malf	10	Moderate	L	Attract
18	F	27	malf	11.25	Severe	L	Connect
19	F	16	malf	5	Severe	R	Attract
20	F	16	malf	8.75	Severe	L	Attract
21	M	15	malf	5	Moderate	L	Attract

BCHD indicates bone-conduction hearing device; COM, chronic otitis media; F, female; L, left; M, male; malf, ear malformation; PTA-BC, bone-conduction pure-tone average; R, right.

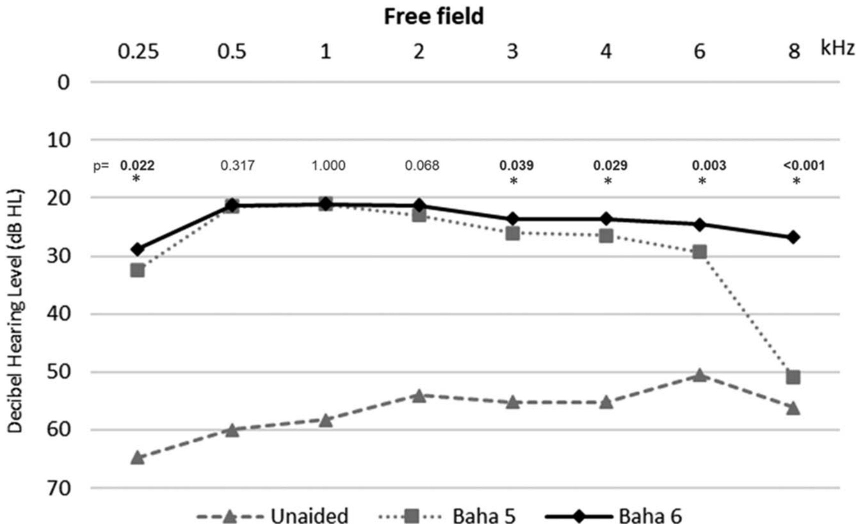

FIG. 2. Mean free-field audiometric thresholds under the three study conditions: unaided, with Baha 5, and with Baha 6 Max. *Statistical difference in the comparison between Baha 5 and Baha 6 Max sound processors (Wilcoxon test).

Table 2 presents the results from the speech recognition evaluation performed using HINT, under the three study conditions, with Baha 5 and Baha 6 Max SP.

Figure 3 shows the comparison of audiometric thresholds by processor model: Attract or Connect.

Table 3 presents the results from the speech recognition evaluation performed with HINT, under the three study conditions, with Baha 5 and Baha 6 Max, by BCHD (Baha Attract or Baha Connect).

Based on the participants' subjective preference reported at the end of the tests, 20 individuals (95%) preferred the Baha 6 Max device, and only 1 individual preferred the Baha 5 device. As explained in the Materials and Methods section, because all patients would ultimately receive the Baha 6 Max processor, the patient who preferred Baha 5 was followed up for potential complaints with Baha 6 Max. Notably, when the device was implanted, the patient no longer preferred Baha 5. The subjective factors that influenced the preference for the Baha 6 Max device mainly included better sound quality, in terms of clarity and comfort, and easier recognition of phrases in noisy environments.

DISCUSSION

The present study compared the hearing performance and speech recognition of two BCHDs—Baha 6 Max, which has a broader FR and higher gain and MPO than Baha 5—in a group of experienced Baha 4 users. The results revealed that the participants who used Baha 6 Max showed better audiometric thresholds and speech recognition in noisy environments than those who used Baha 5.

The highest audible frequency for people with normal hearing is known to be approximately 20 kHz. However, the upper threshold of the FR of most hearing aids remains limited to 4 or 5 kHz (11). Nevertheless, amplification rules prescribe large amounts of gain toward partly restoring, even minimally, audibility at frequencies greater than 5 kHz. Gain in this FR is necessary because the spectral energy of speech is lower for high frequencies than for low or medium frequencies (12–14).

However, large high-frequency gains are still difficult to achieve, with the available technology, mainly because of problems with acoustic feedback. Although little is known about the limitations of BCHDs, the limitation of high-frequency gain is not exclusive to conventional hearing aids. An obvious solution would be to extend the FR of hearing aids beyond what is currently available. Recently, this strategy was applied to a new model of a BCHD SP, whose FR (previously available up to 7000 Hz in the Baha 5 version) increased up to 9700 Hz (in the Baha 6 Max version), in the tireless quest to improve the capture of sounds in this region.

As shown by analyzing the mean free-field pure-tone audiometry thresholds for each frequency (Fig. 2), the results

TABLE 2. *HINT results with Baha 5 and with Baha 6 Max*

HINT Condition	Processor	Average	Median	SD	CI	*p*
SNR 180 degrees (adaptive), dB	Baha 5	−1.32	−1.35	4.37	1.87	0.001*
	Baha 6	−2.95	−2.35	4.35	1.86	
SNR 0 degree (adaptive), dB	Baha 5	−2.89	−3.65	1.97	0.84	<0.001*
	Baha 6	−4.12	−4.75	1.78	0.76	
SNR 0/180 degrees (fixed), %	Baha 5	60.15	66.27	28.36	12.13	<0.001*
	Baha 6	68.79	79.25	26.15	11.19	

CI indicates confidence interval; HINT, hearing in noise test; SD, standard deviation; SNR, signal-to-noise ratio.
*Statistical difference in the comparison between Baha 5 and Baha 6 Max audio processors (Wilcoxon test).

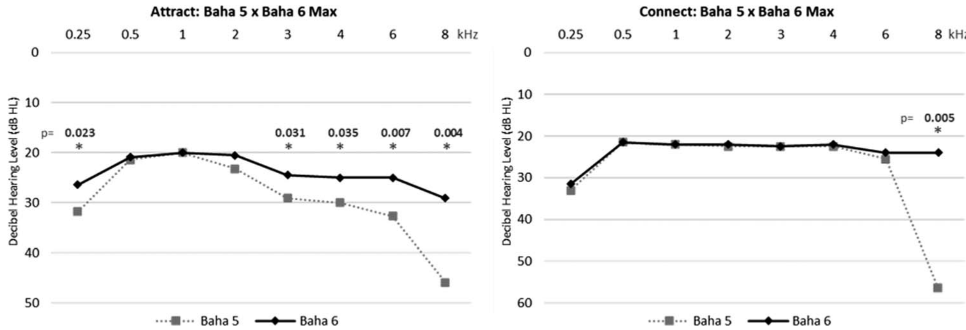

FIG. 3. Mean free-field audiometric thresholds by device. On the left side, Baha 5 attract compared with Baha 6 Max attract. On the right side, Baha 5 connect compared with Baha 6 Max connect. *Statistical difference in the comparison between Baha 5 and Baha 6 max SP (Wilcoxon test).

with Baha 6 Max were significantly better than those with the Baha 5 at 0.25, 3, 4, 6, and 8 kHz, and the greatest difference was observed at 8-kHz frequency (51.0 dB with Baha 5 and 26.7 dB with Baha 6 Max). According to Snapp and Kuzbyt (14), improving hearing outcomes in frequencies greater than 4 kHz provides a better access to a high-frequency bandwidth, which helps to improve speech recognition. Thus, clear differences in electroacoustic characteristics of SPs account for the lower audiometric thresholds and therefore higher gain, especially high-frequency gain (Baha 5–106 dB MPO and 250–7000 Hz FR; Baha 6 Max–113 dB MPO and 200–9700 Hz FR).

The contribution of high-frequency (>5000 Hz) hearing to speech recognition has been extensively studied, and evidence has already been published (12,14–17). A better perception of high-frequency sounds will improve the detection and discrimination of phonemes with high-frequency energy, mainly in poor hearing situations with competitive noise (15,18,19).

Loudness perception may also vary with audible bandwidth. Different studies of loudness and bandwidth with acoustic hearing aids found that higher-frequency components of broadband sounds, when audible, can increase loudness perception particularly for high-level sounds (18,20,21).

This improvement was observed in the auditory evaluations of speech recognition in noisy environments in the present study. The results revealed that Baha 6 Max significantly outperformed Baha 5 under all test conditions. Related results have already been reported by Hua et al. (9), Gawliczek et al. (22), Bosman et al. (23), and Hodgetts et al. (24) and confirm the superior electroacoustic characteristics of Baha 6 Max. As shown by the audiometric thresholds results, the wider FR (up to 9700 Hz on the Baha 6 Max) and consequently the greater high-frequency gain were the determining factors for the superior performance of Baha 6 Max in noisy environments.

Considering that our participants had a mean bone conduction of 9.6 dB, their hearing is much more similar to that of a normal listener, owing to its sensorineural integrity, than to that of individuals with sensorineural HL, in whom sound amplification does not suffice. With this reasoning, the improvement in speech recognition with the wider FR device in noisy environments may be explained by the results observed in previous studies. Notably, high-frequency acoustic information has been found to be beneficial for individuals with normal speech recognition (12,25).

The broader FR enables a greater high-frequency gain. The gain provided in this FR is crucial for speech recognition in noisy environments because, naturally, the spectral energy of speech is weaker at high frequencies than at low or medium frequencies (13).

In comparison with the improvements obtained in the other studies, the relatively small improvement in signal-to-noise ratio of 1.2 dB that was assessed in the present study was expected, according to Bosman et al. (23) and Gawliczek et al. (22). This is because the highest improvements are observed in participants with the worst sensory components. The study by Bosman et al. (23) included a

TABLE 3. *HINT results in Baha Attract and Baha Connect users, with Baha 5 and Baha 6 Max*

HINT Condition	BCHD	N	Processor	Average	Median	SD	CI	*p*
SNR 180 degrees (adaptive), dB	Attract	11	Baha 5	−1.70	−1.80	4.45	2.63	0.013*
			Baha 6	−3.48	−3.55	3.80	2.25	
	Connect	10	Baha 5	−0.91	−1.00	4.48	2.78	0.014*
			Baha 6	−2.37	−2.03	5.03	3.12	
SNR 0 degree (adaptive), dB	Attract	11	Baha 5	−3.27	−3.65	1.68	0.99	0.021*
			Baha 6	−4.14	−4.75	1.71	1.01	
	Connect	10	Baha 5	−2.48	−3.25	2.27	1.41	0.007*
			Baha 6	−4.10	−4.75	1.94	1.21	
SNR 0/180 degrees(fixed), %	Attract	11	Baha 5	64.40	71.88	24.37	14.40	0.003*
			Baha 6	74.11	83.84	22.47	13.28	
	Connect	10	Baha 5	55.48	57.56	32.88	20.38	0.028*
			Baha 6	62.94	63.04	29.77	18.45	

CI indicates confidence interval; BCDH, bone-conduction hearing device; HINT, hearing in noise test; SD, standard deviation; SNR, signal-to-noise ratio.
*Statistical difference in the comparison between Baha 5 and Baha 6 Max audio processors (Wilcoxon test).

group of participants with mild-to-moderate sensorineural HL (median bone conduction, 42.8 dB HL), whereas our participants had well-preserved bone-conduction thresholds, averaging 9.6 dB HL (ranging from 5 to 28.7 dB HL). Gawliczek et al. (22) commented that more robust speech recognition improvements are understandably observed in narrower dynamic ranges. In conventional devices, the sound signal is likely perceived with much more distortion, because most of the amplified signal approaches the MPO. If the device with a wider range and higher high-frequency gain were tested in patients with a narrow dynamic range, distortions could be minimized, because high-frequency dynamic range partly increases, which facilitates the capture of acoustic cues in this FR.

As mentioned previously, higher MPOs have the benefit of promoting, at least theoretically, higher gains with lower distortions. Higher MPO levels may only partly account for the improved speech recognition that is repeatedly found with more powerful SP. (23) The higher gains enabled by these SP may also account for this benefit.

Thus, for patients with conductive HL without sensorineural impairment, as in the present study, high-frequency gain is crucial for improving speech recognition in noisy environments because the main differences in audiometric thresholds were observed in the high-frequency region (3–8 kHz). Conversely, for patients with mixed HL with narrow dynamic ranges, that is, loss with a clear sensorineural component, higher MPO plays a role as important as FR in improving hearing performance by expanding auditory bandwidth.

Previous studies showed that the benefit of high-frequency audibility is not limited to cases of conductive and mixed HL. Investigating the influence of bandwidth on suprathreshold measures of speech understanding and discrimination in adults with sensorineural HL, they have shown that providing extended high-frequency amplification to adults with HL can improve speech understanding in both quiet and noise (12,15,17,18,25,26). It is important to emphasize that those benefit provided by the extended high frequencies cannot be observed on more severe HLs or on the presence of cochlear dead regions (26).

Studies have also shown that degree of HL can influence sound quality and preference for extended bandwidth. Most studies have shown either subjective preference and higher sound quality, or no significant aversion to the provision of extended high frequencies in listeners with normal hearing and less severe HLs (15,18,25,27–29).

Lastly, we also compared differences regarding the type of coupling used, to extrapolate the results for both technologies. Considering only the transcutaneous system (Baha Attract), the Baha 6 Max device provided significantly better speech recognition under the three conditions and audiometric thresholds at frequencies of 0.25, 3, 4, 6, and 8 kHz. Similar results were also observed when comparing the percutaneous system (Baha Connect), in which speech recognition was significantly better with Baha 6 Max than with Baha 5 under the three study conditions, as well as the audiometric thresholds at 8-kHz frequency.

Thus, the electroacoustic characteristics of the Baha 6 Max system improve audiological results, regardless of the coupling system, whether percutaneous or transcutaneous.

Final Considerations

The objective of this study was not to separate the contribution of each electroacoustic characteristic to the result, and the results were attributed to the technological set available in the most recent SP without distinguishing which of them contributed more to improving the results (higher MPO, higher FR, or, accordingly, higher gain). Notably, although the laboratory analysis of the effect of each parameter is crucial for developing knowledge and technology, the device is already commercially available.

Despite studying a small sample of experienced users, this study showed satisfactory and consistent results for a new technology BCHD barely studied and referred to in the literature to date. Based on our data, we think that the Baha 6 Max may be a good therapeutic option owing to excellent functional gain and speech perception in noise results. Future trials with a larger sample size should be relevant to demonstrate and strengthen the audiological results of this device with greater accuracy and certainty.

CONCLUSIONS

The most current, Baha 6 Max SP, has superior acoustic characteristics, and patients with implants experience better audiological results with Baha 6 Max than with Baha 5. The functional gain provided by Baha 6 Max was greater than that provided with the previous version, especially at high frequencies, and speech recognition in noisy environments was also better with the Baha 6 Max device than with Baha 5, owing to its wider FR and higher MPO.

REFERENCES

1. Asma A, Ubaidah MA, Hasan SS, et al. Surgical outcome of bone anchored hearing aid (Baha®) implant surgery: A 10 years' experience. *Indian J Otolaryngol Head Neck Surg* 2013;65:251–4.
2. Iseri M, Orhan KS, Tuncer U, et al. Transcutaneous bone-anchored hearing aids versus percutaneous ones: Multicenter comparative clinical study. *Otol Neurotol* 2015;36:849–53.
3. Dimitriadis PA, Farr MR, Allam A, Ray J. Three year experience with the cochlear Baha® attract implant: A systematic review of the literature. *BMC Ear Nose Throat Disord* 2016;16:12.
4. den Besten CA, Monksfield P, Bosman A, et al. Audiological and clinical outcomes of a transcutaneous bone conduction hearing implant: Six-month results from a multicentre study. *Clin Otolaryngol* 2019;44: 144–57.
5. Flynn MC, Sammeth C, Sadeghi A, et al. Baha® for single-sided sensorineural deafness: Review and recent technological innovations. *Semin Hear* 2010;31:326–49.
6. Bonne NX, Hanson JN, Gauvrit F, Risoud M, Vincent C. Long-term evaluation of sound localisation in single-sided deaf adults fitted with a BAHA® device. *Clin Otolaryngol* 2019;44:898–904.
7. de Wolf MJF, Hendrix S, Cremers CWRJ, Snik AFM. Better performance with bone-anchored hearing aid than acoustic devices in patients with severe air-bone gap. *Laryngoscope* 2011;121:613–6.
8. Mylanus EA, van der Pouw KC, Snik AF, Cremers CW. Intraindividual comparison of the bone-anchored hearing aid and air-conduction hearing aids. *Arch Otolaryngol Head Neck Surg* 1998;124:271–6.

9. Hua H, Goossens T, Lewis AT. Increased maximum power output may improve speech recognition with bone conduction hearing devices. *Int J Audiol* 2022;61:670–7.
10. Bevilacqua MC, Banhara MR, Costa EA, Vignoly AB, Alvarenga KF. The Brazilian portuguese hearing in noise test (HINT). *Int J Audiol* 2008;47:364–5.
11. Aazh H, Moore BCJ, Prasher D. The accuracy of matching target insertion gains with open-fit hearing aids. *Am J Audiol* 2012;21: 175–80.
12. Levy SC, Freed DJ, Nilsson M, Moore BCJ, Puria S. Extended high-frequency bandwidth improves speech reception in the presence of spatially separated masking speech. *Ear Hear* 2015;36:e214–24.
13. Moore BC, Stone MA, Fullgrabe C, Glasberg BR, Puria S. Spectro-temporal characteristics of speech at high frequencies, and the potential for restoration of audibility to people with mild-to-moderate hearing loss. *Ear Hear* 2008;29:907–22.
14. Snapp HA, Kuzbyt B. Effects of extended high frequency bandwidth in osseointegrated bone conduction device users. *Hear Res* 2022; 421:108379.
15. Fülgrabe C, Baer T, Stone MA, Moore BCJ. Preliminary evaluation of a method for fitting hearing aids with extended bandwidth. *Int J Audiol* 2010;49:741–53.
16. Monson BB, Rock J, Schulz A, Hoffman E, Buss E. Ecological cocktail party listening reveals the utility of extended high-frequency hearing. *Hear Res* 2019;381:107773.
17. Hornsby BW, Ricketts TA. The effects of hearing loss on the contribution of high- and low-frequency speech information to speech understanding. *J Acoust Soc Am* 2003;113:1706–17.
18. Van Eeckhoutte MV, Folkheard P, Glista D, Scollie S. Speech recognition, loudness, and preference with extended bandwidth hearing aids for adult hearing aid users. *Int J Audiol* 2020;59:780–91.
19. Hornsby BW, Ricketts TA. The effects of hearing loss on the contribution of high- and low-frequency speech information to speech understanding. II. Sloping hearing loss. *J Acoust Soc Am* 2006;119:1752–63.
20. Jesteadt W, Walker SM, Ogun OA, et al. Relative contributions of specific frequency bands to the loudness of broadband sounds. *J Acoust Soc Am* 2017;142:1597–610.
21. Vaisberg J, Folkeard P, Levy S, et al. Sound quality ratings of amplified speech and music using a direct drive hearing aid: effects of bandwidth. *Otol Neurotol* 2021;42:227–34.
22. Gawliczek T, Wimmer W, Caversaccio M, Kompis M. Influence of maximum power output on speech understanding with bone anchored hearing systems. *Acta Otolaryngol* 2020;140:225–9.
23. Bosman AJ, Kruyt IJ, Mylanus EAM, Hol MKS, Snik AFM. Evaluation of an abutment-level superpower sound processor for bone-anchored hearing. *Clin Otolaryngol* 2018;43:1019–24.
24. Hodgetts WE, Hagler P, Hakansson BEV, Soli SD. Technology-limited and patient-derived versus audibility-derived fittings in bone-anchored hearing aid users: A validation study. *Ear Hear* 2011;32:31–9.
25. Moore BCJ, Füllgrabe C, Stone MA. Effect of spatial separation, extended bandwidth, and compression speed on intelligibility in a competing-speech task. *J Acoust Soc Am* 2010;128:360–71.
26. Hornsby BW, Johnson EE, Picou E. Effects of degree and configuration of hearing loss on the contribution of high- and low-frequency speech information to bilateral speech understanding. *Ear Hear* 2011;32:543–55.
27. Seeto A, Searchfield GD. Investigation of extended bandwidth hearing aid amplification on speech intelligibility and sound quality in adults with mild-to-moderate hearing loss. *J Am Acad Audiol* 2018;29:243–54.
28. Moore BJ. Effects of bandwidth, compression speed, and gain at high frequencies on preferences for amplified music. *Trends Amplif* 2012; 16:159–72.
29. Arbogast TL, Moore BCJ, Puria S, et al. Achieved gain and subjective outcomes for a wide-bandwidth contact hearing aid fitted using CAM2. *Ear Hear* 2019;40:741–56.