Benefit of Higher Maximum Force Output in Bone Anchored Hearing Systems: A Crossover Study

*Elin Bergius, †Marianne Philipsson, †Tove Rosenbom, and *‡André Sadeghi

*Region Västra Götaland, Habilitation & Health, Hearing Organization, Gothenburg, Sweden; †Oticon Medical AB, Askim, Sweden; and †Unit of Audiology, Department of Health and Rehabilitation, Institute of Neuroscience and Physiology, Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden

Objective: To investigate how higher maximum force output (MFO) in bone anchored hearing systems (BAHS) affects perceived benefit and the subjective experience of sound as well as hearing outcomes in subjects with mixed hearing loss.

Study Design: Prospective single-centered, randomized crossover design (A-B-A) with within-subject control design.

Patients: The study included 19 experienced BAHS users with mixed hearing loss in the fitting range of a standard BAHS.

Interventions: The study evaluated two sound processors with differing MFOs and sizes—Device A: standard sound processor with a lower MFO and Device B: superpower sound processor with a higher MFO.

Outcome Measures: Speech recognition in noise at different signal to noise ratios, aided thresholds, and questionnaires.

Results: Speech recognition test showed significant improvements using Device B compared with Device A at both 78 dB SPL (mean difference: 9%) and 75 dB SPL (mean difference: 12%) (p < 0.05). Moreover, speech, spatial, and qualities of hearing scale (SSQ12-C) showed a significantly greater perceived benefit with Device B concerning spatial abilities (mean: 0.5–0.6) (p < 0.05). At the conclusion of the study, 58% of participants chose to keep Device A for further use. The main reasons for this were the size of the sound processor and a more comfortable sound experience.

Conclusions: A BAHS sound processor with a higher MFO leads to improved speech-in-noise performance in loud/noisy listening situations and is perceived as significantly better to process spatial information in daily listening situations. However, the relation between cosmetics and performance is not straightforward, and several factors seem to affect the selection process of BAHS. Key Words: Bone anchored hearing aids—Maximum force output—Mixed hearing loss.

Otol Neurotol 42:1451–1459, 2021.

Bone anchored hearing systems (BAHS) are a rehabilitation alternative for patients with conductive, mixed hearing loss, or single sided deafness (1,2). A percutaneous BAHS consists of an external sound processor that picks up sound and converts it into mechanical vibrations. These vibrations are then transmitted to a skin penetrating abutment and an implant, and onward through the temporal bone to the inner ear (3).

BAHS sound processors differ in size, design, and maximal force output (MFO). MFO is the maximal level of force that the sound processor can transmit to the temporal bone without distortion (4). The MFO in modern BAHS sound processor is controlled by signal processing. When the output signal reaches the MFO, it will be quickly attenuated in that frequency band, such that physical saturation of the transducer never occurs. The high compression ratio will introduce some artifacts, which may affect speech recognition and sound quality (5). To date, all BAHS available in the market have a MFO that are below listeners’ loudness discomfort levels and limited MFO leads to a reduced auditive dynamic range but also prevents loud sounds reaching an uncomfortable level (6–9). In general, larger sound processors with larger vibrators provide a higher MFO and, as such, allows the reproduction of a larger proportion of the auditive dynamic range, therefore sounds are reproduced more naturally without being distorted with this kind of device (6,7).

A higher MFO in BAHS sound processors has been shown to improve speech understanding in noise at normal conversation levels for people with mixed hearing loss (10) and reduce listening effort when measured with pupillometry, as a consequence of fewer saturation artifacts (5). Moreover, a study of Bosman et al. (8)
concluded that a higher MFO in BAHS sound processors is perceived as providing greater assistance in receiving spatial information and is preferred when listening to speech in large groups and music.

Theoretically, most BAHS users should benefit from the larger dynamic hearing range provided by the device’s higher MFO. However, it is possible that other factors may influence the patient’s choice of device, such as cosmetic considerations. Research has earlier been done to investigate how a higher MFO affects the user’s experience and device performance (5,8–10), although the effects have not yet been fully explored. Patient benefits stemming from a higher MFO as compared with their feelings concerning the cosmetic aspects of a BAHS have never been investigated. Research with a clinical focus covering the benefits of a higher MFO and subjective parameters is needed to support audiologists and patients in making important decisions concerning treatment options.

This study investigated how higher MFO affects the perceived benefit in daily life in relation to the cosmetic aspect of the sound processor in experienced BAHS users with mixed hearing loss. It was hypothesized that the hearing performance is better and the perceived benefit in daily life is greater with the sound processor with higher MFO, which would be preferred over the smaller sound processor with lower MFO despite the difference in appearance. For this purpose, two BAHS sound processors that differed in size and MFO were evaluated. A randomized crossover design (A-B-A) was used with three trial periods where all participants evaluated both sound processors. The study’s primary objective was to investigate the effect of MFO on perceived benefit in subjects with mixed hearing loss. The secondary objective was to examine which sound processor was preferred when both aesthetics and perceived benefit were considered. The tertiary objective was to examine the aided thresholds and the effect of MFO on speech recognition.

**MATERIALS AND METHODS**

**Study Population and Ethics**

Nineteen BAHS users (8 women, 11 men) with a mixed hearing loss were recruited from the patient database at the Hearing Organization, Västra Götaland, Sweden. The participants were between 46 and 76 years old (mean 67, SD 7.0 yr). Demographics for the included subjects are shown in Table 1. All participants had a bilateral hearing loss and were unilaterally fitted with a BAHS device. At the implanted side they had a mixed hearing loss in the fitting range of a standard BAHS (pure tone average [PTA] 0.5, 1, 2 and 3 kHz).

![TABLE 1. Demographic data concerning the study group](image)

```
| ID | Age | Sex | Hearing Loss | Side | Prior Device | Opposite Ear | Fitted Ear | Opposite Ear | Fitted Ear |
|----|-----|-----|--------------|------|--------------|--------------|------------|--------------|------------|
| 1  | 73  | M   | Mastoidectomy | R    | OM Ponto P   | A            | 58.8       | 50           | 21.3       |
| 2  | 65  | F   | Otosclerosis  | R    | OM Ponto Pro | U            | 60         | >110         | 33.8*      |
| 3  | 55  | M   | Mastoidectomy | L    | OM Ponto Pro | U            | 61.3       | 21.3         | 21.3       |
| 4  | 61  | F   | Mastoidectomy | L    | OM Ponto Plus P | A            | 87.5       | 52.5         | 31.3       |
| 5  | 71  | M   | Mastoidectomy | L    | OM Ponto Plus | U            | 78.8       | 27.5         | 28.8       |
| 6  | 64  | F   | Mastoidectomy | L    | OM Ponto Plus | U            | 41.3       | 35           | 21.3       |
| 7  | 67  | F   | Mastoidectomy | R    | OM Ponto Pro | U            | 68.8       | 23.8         | 25         |
| 8  | 76  | M   | Mastoidectomy | L    | OM Ponto Plus P | U            | 75         | 40           | 38.8       |
| 9  | 70  | M   | Mastoidectomy | L    | OM Ponto Pro | A            | 73.8       | 43.8         | 40         |
| 10 | 72  | F   | Mastoidectomy | L    | OM Ponto Pro | U            | 43.8       | 20           | 23.8       |
| 11 | 69  | M   | Mastoidectomy | L    | Cochlear Baha 5 | U            | 55         | 61.3         | 30         |
| 12 | 63  | M   | Mastoidectomy | R    | OM Ponto P   | U            | 63.8       | >110         | 31.3*      |
| 13 | 69  | F   | Mastoidectomy | L    | OM Ponto Plus | U            | 55         | 36.3         | 33.8       |
| 14 | 72  | M   | Mastoidectomy | L    | Cochlear Baha 5 | A            | 62.5       | 36.3         | 33.8       |
| 15 | 68  | F   | Chronic otitis | R    | OM Ponto Plus | A            | 62.5       | 52.5         | 30         |
| 16 | 67  | M   | Mastoidectomy | L    | Cochlear Baha 5 | A            | 77.5       | 41.3         | 41.3       |
| 17 | 72  | M   | Chronic otitis | L    | OM Ponto Plus P | A            | 58.8       | 62.5         | 36.3       |
| 18 | 68  | M   | Otosclerosis  | R    | Cochlear Intenso | A            | 85         | 56.3         | 38.8       |
| 19 | 46  | F   | Atresia       | L    | OM Ponto Plus | A            | 97.5       | 22.5         | 28.8       |
```

*Either not masked due to overmasking, or inapplicable due to sensorineural hearing loss.

A indicates aided; AC, air conduction; BC, bone conduction; F, female; L, left; M, male; R, right; U, unaided. PTA 0.5, 1, 2 and 3 kHz.
and Ponto 3 SuperPower (Device B). Device B’s peak MFO at an input level of 90 dB SPL is 11 dB higher than that of device A. Device B is also 3 mm higher and 3 g heavier than Device A.

The sound processors were programmed according to the manufacturer’s instructions (11) using the Genie Medical 2016.1 software distributed by Oticon Medical AB. Feedback measurement was performed, and the gain was calculated according to the modified prescription formula NAL-NL 1 based on measured BC in-situ thresholds. When necessary, the gain was fine-tuned to the participant’s preferred level and the same adjustments were made in both devices. Four participants required an increase in gain of 1 to 8 dB. One participant (No. 19) was dissatisfied with the gain level of the first fit, which was subsequently adjusted by -12 dB to achieve an acceptable level.

According to datalogging, participants used Device A for 3 to 20 hours per day (mean: 10.6 h) and Device B for 3 to 24 hours per day (mean: 10.1 h) during the trial periods. The volume control remained activated and the noise reduction and directional settings remained unchanged from the standard setting during the trial periods. During the sound field measurements in the clinic, the sound processors were set to omni-directional mode and its noise reduction and digital feedback cancellation function were switched off.

**Procedure**

The study used a prospective single-center, randomized crossover design (A-B-A) (12) with within-subject control. The study consisted of four visits and three trial periods for each test person. The participants were randomized into two

---

**FIG. 1.** Panel A shows mean bone conducted (BC) thresholds and Panel B shows mean air conducted (AC) thresholds on the implanted side for the study’s 19 participants. Participants individual thresholds are shown in gray lines. The error bars represent ±1 standard deviation.
groups. Group 1 evaluated the sound processors in the order A-B-A and group 2 in reverse order B-A-B. Each trial period was approximately 2 weeks.

At the first visit, a detailed description of the study was provided, and informed consent was obtained. Moreover, standard pure tone audiometry and unaided sound field measurements were performed. Participants were then fitted with one of the two sound processors which depended on the study group (1 or 2). Thereafter, the first trial period started, and all participants tried out the first sound processor in their daily life. At the second visit, the second sound processor was fitted and evaluated for 2 weeks. At the third visit, participants were fitted again with the first sound processor. During the second and third trial period participants evaluated their experiences by filling in the questionnaire. Speech, Spatial and Qualities of hearing scale (SSQ-12) (13) based on their experiences with the sound processor used. At the final visit, participants evaluated the two devices by filling in two questionnaires, a comparative version of SSQ-12 and a specially designed questionnaire where the two devices were compared. Finally, aided sound field thresholds and the Hearing In Noise Test (HINT) (14) were performed with both sound processors.

Audiological Measurements

All measurements were conducted in a soundproof room using a calibrated audiometer (Astera, Madsen). Pure tone audiometry was performed using TDH-39 earphones and B-71 bone conductor and according to the standardized method described in the ISO standard 8253–1 (15). Sound field measurements were performed using a loudspeaker (Canton PTA/ML, Weilrod, Germany) placed 1 m in front of the participant and the opposite ear was sealed by placing an earplug (Cirrus Health Care Products, Kent, UK) inside the ear canal and an earmuff (Peltor Optime III, Värnamo, Sweden) over the pinna.

Effective gain is defined as the relation between the bone conduction threshold and the aided threshold (16) and was calculated as the difference in dB between BC in-situ threshold and aided threshold.

Speech perception in noise was measured with a Swedish version of HINT (16) with a S0N0 loudspeaker setup at four fixed signal-to-noise ratios (SNR). The noise was fixed at a level of 75 dB SPL while speech was presented by a female speaker at four levels, 78, 75, 72, and, 70 dB SPL, resulting in signal-to-noise ratios (SNR) of +3, 0, –3, and –5 dB, respectively. The results of the HINT measurement were defined as the percent of correct responses obtained at each level.

Questionnaires

The SSQ-12 (13) is a standardized questionnaire, specialized to target how speech is perceived in easy and complex listening situations as well as perception of sound quality and the effect of the sound source’s distance, direction, and movement. A Swedish version was used in the study. Participants responded to each question concerning their daily life experience using a visual analog scale ranging from 0 (not at all) to 10 (perfectly).

The SSQ12-C is a comparative version of SSQ12 and evaluates speech, spatial, and sound quality perception in different listening situations based on comparing two different sound processors. The questionnaire consists of the same questions as SSQ12, with ratings from –5 to +5. The rating –5 indicate a strong preference for Device A where +5 indicate a strong preference for Device B. No preferred difference was indicated by rating 0, located in the middle of the scale.

The two sound processors were also compared using a questionnaire custom-designed for this study in which the categorical ratings were “much better,” “better,” and “no difference.” The questionnaire covered aspects such as speech comprehension in quiet and noisy environments, listening to music, sound quality, sound comfort, listening effort, and aesthetics. The participants were also asked to select the sound processor they would prefer to use in daily life. Finally, they were also asked to specify the main reasons for their choice.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics, version 25. The nonparametric test Wilcoxon signed-rank test (17) was used to analyze all test outcomes except for the custom-designed questionnaire, for which the sign test was used. All significance tests were two-sided and conducted at the 5% significance level (p < 0.05).

RESULTS

Questionnaire Assessment

The self-reported ratings for the SSQ-12 questionnaire showed similar ratings for both sound processors in all the daily listening situations considered in the questionnaire. This was also revealed in the statistical analysis where no significant differences were found between the ratings obtained after the trial period with Device A and Device B (data not shown). Hence, these results indicate that the perceived benefit in the daily life was similar with the two devices.

Figure 2 shows the response distribution obtained with the SSQ12-C questionnaire for each of the questions. The statistical analysis revealed that the perceived benefits were not significantly different between Device A and Device B, except for two listening conditions where Device B was rated significantly better than Device A: localization of steady sound source (mean: 0.6, SD 1.0, p = 0.016) and localization of moving sound source (mean: 0.5, SD 1.0, p = 0.043).

Preference

Figure 3 shows the number of subjects for device preference in each of the listening conditions and attributes evaluated in the custom-designed questionnaire. A strong preference was only observed when evaluating the cosmetic attribute where 11 out of 19 participants preferred Device A over Device B (p < 0.001). For the other nine questions, no significant differences were obtained between Device A and Device B.

After completing the study, 11 participants (58%) chose Device A and eight participants (42%) chose Device B for further use. The participants reported that the main reasons for selecting Device A were the size of the sound processor and a more comfortable sound experience. Device B was mainly selected due to its better sound quality and better speech perception.

Effective Gain and Speech Recognition

Figure 4 shows the distributions of the effective gain for Device A and Device B. The statistical analysis
revealed no significant differences between the two devices across all frequencies.

Figure 5 shows the results for speech recognition in noise. The statistical analysis revealed a significant difference between speech recognition measured with both devices in comparison with the unaided condition at all four tested levels (for speech at 70, 72, 75, and 78 dB SPL), the mean difference between Device A and unaided were 7.8; 18.4; 28.3 and 30.7%; for Device B and unaided the mean difference were 10.5; 23.8; 40.3; and 39.5% ($p < 0.001$). Comparing the two devices, the speech recognition was general higher when tested with Device B than with Device A. Statistically significant differences was found between sound processors when speech was presented at 78 dB SPL (mean difference: 8.8%, SD 14.5%, $p = 0.014$) and 75 dB SPL (mean difference: 12%, SD 11.1%, $p = 0.002$) which are the conditions with highest presentation levels and better SNRs. Hence these results indicate that the device with higher MFO improves speech recognition in noise for louder presentation levels.

FIG. 2. Results for the comparative version of speech, spatial and qualities of hearing scale (SSQ12-C). The whiskers show minimum and maximum values, excluding outliers. Outliers are represented by circles and extreme outliers are shown with asterisks. The boxes range from the first to the third quartiles. There was significant better result for Device B compared with Device A at question 6 localization (mean: 0.6) and question 7 distance and movement (mean 0.5) ($p < 0.05$). There were no significant differences at the other questions.

Figure 2 shows the results for the comparative version of speech, spatial and qualities of hearing scale (SSQ12-C). The whiskers show minimum and maximum values, excluding outliers. Outliers are represented by circles and extreme outliers are shown with asterisks. The boxes range from the first to the third quartiles. There was significant better result for Device B compared with Device A at question 6 localization (mean: 0.6) and question 7 distance and movement (mean 0.5) ($p < 0.05$). There were no significant differences at the other questions.

FIG. 3. Device preferences for 10 categories, presented in terms of the number of subjects related to the preferred sound processor for each category. Differences between the two devices were not significant at any question except the question concerning cosmetics, Device A was preferred by 58% ($n = 11$) of the participants and no subject preferred Device B ($p < 0.001$).
Preferred Sound Processor and HINT Measurements

A clear relation between the preferred sound processor and speech recognition was obtained for the SNR of +3 dB. Most participants who selected the Device B also exhibited better speech recognition with Device B than with Device A. In contrast, for the SNR of 0 dB condition, the participants selected both devices even though the difference in percentage indicated an improvement with Device B.

Selected Sound Processor and BC Hearing Threshold

Device B was mostly preferred over Device A ($n_{\text{Device B}} = 4$ versus $n_{\text{Device A}} = 1$), for participants with high BC thresholds (PTA above 35 dB HL) whereas for low

---

**FIG. 4.** Effective gain (difference in dB between BC in-situ thresholds and aided thresholds) displayed each device as a function of frequency. The whiskers show minimum and maximum values, excluding outliers. Outliers are depicted by a circle and extreme outliers are shown with an asterisk. The boxes range from the first to the third quartiles. There were no significant differences between devices at any frequency.

**FIG. 5.** Hearing in noise test (HINT) results for unaided, Device A, and Device B expressed in percentage correct repeated words. The whiskers show maximum and minimum values, excluding outliers. Outliers are represented by circles and extreme outliers are shown with asterisks. The boxes range from the first to the third quartiles. The test results showed that Device B significantly outperformed Device A at the levels 75 dB SPL (mean: 12%) and 78 dB SPL (mean: 9%) ($p < 0.05$).
thresholds (PTA below 35 dB HL), most participants preferred Device A over Device B (nDevice A = 10 versus nDevice B = 4). Thus, these results suggest that the MFO of the sound processor plays an important and higher role than the cosmetics in the selection of the device for listeners with high BC hearing thresholds.

**Selected Sound Processor and Hearing Loss on Opposite Side**

The results show that participants with mild hearing loss (AC PTA 20–40 dB HL) on the contralateral ear mostly selected Device A (six out of nine), participants with moderate to moderately severe hearing loss (AC PTA 41–70 dB HL) mostly preferred Device B (five out of eight). Two participants were deaf on the contralateral ear, both preferred Device A.

Some participants used an AC hearing aid (n = 9) on the contralateral ear, while the others were unaided (n = 10). The results show that Device A was mostly selected by the participants that were unilateral fitted (seven out of 10) with a BAHS sound processor, whereas bilateral fitted subjects (BAHS + HA) only showed a slight preference for Device B (five out of nine).

**DISCUSSION**

The objective of this study was to investigate the subjective and objective performances of two BAHS sound processors which differed in size, weight, and MFO. The critical consideration in this context is two-fold: to offer a sound processor that is small enough that patients are willing to wear it, but also powerful enough to reproduce as much as possible of the dynamic range of hearing. Since the low level of MFO in the sound processors in relation to the sound processor’s size is a well-known problem it is important to investigate the benefits of higher MFO in BAHS sound processors.

**Subjective Evaluation**

The results of this evaluation showed that benefit was generally perceived to be similar with both devices. This may be because participants are not commonly exposed in their daily life to listening situations where the difference in MFO represents a significant improvement in the listening experience (i.e., loud levels of sound). However, at SSQ12-C questionnaire, the perceived benefit with Device B was significantly higher for the localization of steady and moving sound sources. This perceived improvement in spatial hearing could presumably be attributed to the higher MFO in Device B since the cues for sound localization were either more accessible, or less likely to be distorted due to a high compression ratio. These findings are consistent with a study of Bosman et al. (8) that showed better performance on the SSQ questionnaire for the device with higher MFO.

**Device Preference**

The results showed that 58% of participants (n = 11) chose the smaller sound processor with lower MFO (Device A) for further use, and the size of the device and a more comfortable sound experience were the reported reasons for their choice. Eight participants (42%) selected the bigger device for further use, because they appreciated more the increase in sound quality. This is in agreement with previous studies that showed the importance of cosmetics in the patient’s choice of device, and that many users prefer smaller and more cosmetically appealing devices (18,19).

Some of the participants reported that Device B generated sharp, uncomfortable sound. Higher MFO in BAHS sound processor should not cause discomfort when listening to loud sounds, since the MFO still is below the uncomfortable level (8,9). This might be explained by the short trial periods and the fact that participants in this study were more accustomed to a diminished aided dynamic range due to their use of a sound processor with a relatively low MFO.

**Hearing Outcomes**

No significant differences were found between the effective gain between the two sound processors. These results show that the same amount of gain for low level sounds was prescribed with the two devices, indicating that the amount of amplification was not a variable in the study and consequently a fair comparison between the devices was conducted.

The evaluation of the speech recognition in noise test showed, as expected, a significant improvement when using both sound processors over the unaided condition. The results also showed improved speech recognition with Device B compared with Device A for the two loudest speech levels (75- and 78-dB SPL). At these high sound levels, Device A is likely in saturation in more frequency bands compared with Device B due to its lower MFO. In Bianchi et al. (5), the sound pressure level for the input speech signal that was chosen to avoid saturation in the second MFO band of Device B was, on average, of 76 dB SPL (68–80 dB SPL, depending on the degree of hearing loss). Hence, speech levels of 75 and 78 dB SPL will likely saturate Device A in its first and second MFO bands for mixed hearing losses and create distortion in the speech signal. It is possible that the distortion is more pronounced and audible at 78 dB SPL, which might also explain the clear preference for Device B for those subjects that had an improved performance with Device B at 78 dB SPL compared with Device A. These results indicate that hearing-impaired listeners will benefit from sound processors with higher MFO in terms of improved speech understanding in loud/noisy listening situations. This is in agreement with previous studies which also reported that sound processors with higher MFO can lead to improved speech recognition (5,10).

The speech and noise levels used in this study were louder than in many conversational situations. These levels were based on the conception that one of the most important conversational situations for hearing aid users is comprehend speech in a noisy environment and the

---

*Otology & Neurotology, Vol. 42, No. 10, 2021*
chosen level should be within what people with hearing loss are often exposed to and experience as challenging during conversation in noise (20, 21).

Trade-off Between Benefit and Cosmetic Appearance

When the relation between the improvement in speech recognition and the choice of device was analyzed, the results for the loudest condition tested (78 dB SPL), revealed that most participants who had an improvement in speech recognition with Device B, also selected this device for further use. In contrast, participants who did not exhibit a substantial improvement in speech recognition with Device A in the loudest test conditions, selected the smaller device. Therefore, the results indicate that most participants with an improvement in speech recognition with Device B (at 78 dB SPL), valued more the better performance of the sound processor provided by the higher MFO than the cosmetics.

Another way to analyze the decision process is considering the degree of BC hearing loss. The result showed that the participants with the larger BC hearing losses mostly preferred Device B despite its bigger size, indicating that higher MFO is preferred since this provides sufficient dynamic range for high degrees of hearing loss. Interestingly, for the smaller degrees of hearing loss, the results did not show a clear tendency in the selection of the device. Thus, this suggests that the degree of hearing loss does not have a big influence in the selection process for users with lower hearing thresholds.

One factor that may also have affected the experience of the devices and the questionnaire results can be the degree of hearing loss in the opposite ear, which varied from mild to profound. Participants with mild hearing loss in the contralateral ear were more likely to prefer Device A, while participants with more severe hearing loss in the opposite ear mostly selected Device B. It is possible that patients with a mild hearing loss on the opposite ear do not depend on the BAHS to the same extent compared with a subject with more severe hearing loss on the opposite ear.

It was hypothesized that listeners would experience a more comfortable and natural sound experience and greater perceived benefit as a result of a higher MFO, and that most participants would thus prefer the sound processor with the higher MFO, despite its larger size. Our hypothesis proved correct for some participants (n = 8). These subjects rated Device B higher in questionnaires, performed better during HINT when using device B, and selected Device B for further use. Some other participants (n = 4) chose to keep Device A despite superior performance and higher questionnaire rating with Device B. This study highlighted some of the trade-offs that the users are willing to make in the selection process, however, the decision is personal. It is expected that the users make the decision as a trade-off between the cosmetics and the benefit provided by the sound processors. For instance, it is likely that participants who did not perceive a high difference in the performance between devices, will select the smaller device, whereas the participants that perceived a substantial improvement with the device with higher MFO, will select the bigger device despite its bigger size. The study did not collect information about the participants listening environment and to what degree they are exposed to loud environments. This assessment would be beneficial in any future study to clarify if there is any relation to participants’ subjective evaluation and preference.

CONCLUSION

The results of this study showed that the sound quality reported after each field trial was perceived to be similar using Device A and Device B. However, a direct comparison of the two sound processors showed that a BAHS with higher MFO is perceived as significantly better to process spatial information in daily listening situations. Additionally, the results showed that a sound processor with a higher MFO leads to improved speech-in-noise performance in loud/noisy listening situation, compared with a sound processor with lower MFO that is likely to be in saturation. Overall, this study showed that the relation between cosmetics and performance is not straightforward, and that several factors seem to affect the selection process of BAHS. Many users preferred a more cosmetically appealing device over higher MFO, especially if they did not perceive any or little difference in daily listening situations with the two devices. However, when the users perceived a higher benefit in speech recognition at high presentation levels, they were willing to sacrifice the device’s appearance for better sound quality. The study also showed that the degree of hearing loss seems to have a big influence in the selection process. Users with higher BC PTA preferred the sound processor with higher MFO, despite its larger size. The results from this study can serve as support for audiologists and patients when deciding treatment options considering the trade-off between the cosmetic aspect and the sound quality and perceived benefit provided by the BAHS sound processor.

REFERENCES

1. Gardell IS, Andresen K, Faber CE, et al. Bone-anchored hearing aids are effective and associated with a high degree of satisfaction. Dan Med J 2015;62(10):508.
2. van Wieringen A, De Voecht K, Bosman A, et al. Functional benefit of the bone-anchored hearing aid with different auditory profiles: objective and subjective measures. Clin Otolaryngol 2011;36(1):114–20.
3. Håkansson B, Tjellström A, Rosenhall U, et al. The bone-anchored hearing aid. Principal design and a psychoacoustical evaluation. Acta Otolaryngol 1985;100:229–39.
4. Dillon H, Storey L. The National Acoustic Laboratories’ procedure for selecting the saturation sound pressure level of hearing aids: theoretical derivation. Ear Hear 1998;19(3):255–66.
5. Bianchi F, Wendt D, Wassard C, et al. Benefit of higher maximum force output on listening effort in bone-anchored hearing system users: a pupillometry study. Ear Hear 2019;40(4):220–32.
6. Zwartenkot JW, Smik AF, Mylanus EA, et al. Amplification options for patients with mixed hearing loss. Otol Neurotol 2014;35(3):221–6.
7. van Barneveld DC, Kok HJW, Noten JFP, et al. Determining fitting ranges of various bone conduction hearing aids. Clin Otolaryngol 2018;43:68–75.
8. Bosman AJ, Kruyt JJ, Mylanus EAM, et al. Evaluation of an abutment-level superpower sound processor for bone-anchored hearing. Clin Otolaryngol 2018;43:1019–24.

9. Bosman AJ, Kruyt JJ, Mylanus EAM, et al. On the evaluation of a superpower sound processor for bone-anchored hearing. Clin Otolaryngol 2018;43:450–5.

10. 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.

11. Genie Medical Fitting Guide. Oticon Medical AB. Available at: https://www.oticonmedical.com/-/media/medical/main/files/for-professionals/bahs/audiological-materials/gm/eng/genie-medical—fitting-guide—english—m52755.pdf?la=en. Accessed October 2018.

12. Byiers BJ, Reichle J, Symons FJ. Single-subject experimental design for evidence-based practice. Am J Speech Lang Pathol 2012;21:397–414.

13. Noble W, Jensen N, Naylor G, et al. A short form of the Speech, Spatial and Qualities of Hearing scale suitable for clinical use: the SSQ12. Int J Audiol 2013;52:409–12.

14. Hällgren M, Larsby B, Arlinger S. A Swedish version of the Hearing In Noise Test (HINT) for measurement of speech recognition. Int J Audiol 2006;45:227–37.

15. ISO Standard: Acoustics — Audiometric test methods — Part 1: Pure-tone air and bone conduction audiometry: ISO 8253-1:2010. Available at: https://www.iso.org/standard/43601.html.

16. Snik A, Maier H, Hodgetts B, et al. Efficacy of auditory implants for patients with conductive and mixed hearing loss depends on implant center. Otol Neurotol 2019;40:450–5.

17. Wilcoxon F, Katti SK, Wilcox RA. Critical values and probability levels for the Wilcoxon rank sum test and the Wilcoxon signed rank test. Selected Tables Math Stat 1970;1:171–259.

18. Tyler RS, Witt SA, Dunn CC. Trade-offs between better hearing and better cosmetics. Am J Audiol 2004;13:193–9.

19. Siau RT, Dhillon B, Siau D, Green KM. Bone-anchored hearing aids in conductive and mixed hearing losses: why do patients reject them? Eur Arch Otorhinolaryngol 2016;273:3117–22.

20. Wolters F, Smeds K, Schmidt E, et al. Common sound scenarios: a context-driven categorization of everyday sound environments for application in hearing-device research. J Am Acad Audiol 2016;27:527–40.

21. Wagener KC, Hansen M, Ludvigsen C. Recording and classification of the acoustic environment of hearing aid users. J Am Acad Audiol 2008;19:348–70.