The Journal of International Advanced Otology

J Int Adv Otol 2024; 20(6): 502–506 • DOI: 10.5152/iao.2024.241565

Original Article

Consideration of Sufficient and Insufficient Benefits in Hearing Aid Fitting

Yoshihiro Nitta[1], Hajime Sano[2], Shogo Furuki[3], Sachie Umehara[4], Yuki Hara[2], Taku Yamashita[1]

[1]Department of Otorhinolaryngology and Head and Neck Surgery, Kitasato University School of Medicine, Kanagawa, Japan
[2]Department of Rehabilitation, Kitasato University School of Allied Health Sciences, Kanagawa, Japan
[3]Furuki Otorhinolaryngology Clinic, Kanagawa, Japan
[4]Department of Rehabilitation, Kitasato University Hospital, Kanagawa, Japan

ORCID IDs of the authors: Y.N. 0000-0003-4260-4673, H.S. 0000-0002-0645-2521, S.F. 0000-0001-5873-8604, S.U. 0000-0002-6290-2187, T.Y. 0000-0003-0441-2611.

Cite this article as: Nitta Y, Sano H, Furuki S, Umehara S, Hara Y, Yamashita T. Consideration of sufficient and insufficient benefits in hearing aid fitting. *J Int Adv Otol.* 2024;20(6):502-506.

BACKGROUND: During hearing aid (HA) fitting, individuals may experience better speech discrimination at normal speech levels and worse discrimination at loud speech levels than without an HA. Therefore, we investigated factors that worsen speech discrimination when the speech sound level increases.

METHODS: Speech discrimination was measured in patients aged >20 years who had average hearing thresholds <90 dB on pure-tone audiometry. An insufficient benefit was defined as speech discrimination being better at 65 dB sound pressure level (SPL) with HAs than without HAs and worse at 80 dB SPL.

RESULTS: Of the 251 participants (296 ears), 229 and 25 had sufficient benefit and insufficient benefit, respectively. Functional gains (FGs) of sufficient benefit were approximately 1/3 gain (1/3 G) at 500 and 4000 Hz and slightly larger at 1000 and 2000 Hz. Functional gains of insufficient benefit were approximately 1/2 G at 1000 and 2000 Hz, smaller at 500 and 4000 Hz, and approximately 1/3 G at 250 Hz. Moreover, the difference between 1/2 G and FG was significantly larger in the sufficient benefit group at 250 500, and 4000 Hz than in the insufficient benefit group. Additionally, the average compression ratio at 50-80 dB SPL in the insufficient benefit group was approximately 1.1 to 1.2, slightly lower than the standard values.

CONCLUSION: Adjusting the compression ratio and lowering the FG to approximately 1.5 and 1/3 G, respectively, may help improve speech discrimination if it worsens with increasing sound levels during HA fitting.

KEYWORDS: Hearing aids, prosthesis fitting, speech discrimination

INTRODUCTION

Hearing aid (HA) fitting involves selecting and configuring a suitable HA for patients with hearing loss (HL). In Japan, the guidelines for evaluating HA fitting (2010)[1] are used to assess the effectiveness of HA use. At our HA outpatient clinic, we select an appropriate HA for patients with HL and perform the initial setup. Moreover, we measure the hearing thresholds in a sound field with the HA, adjust the gain, and help the patient to start wearing the HA. After 1 or 2 weeks, the wearing status of the patient is checked, and the HA is adjusted if required. This iterative process continues for approximately 3 months to fine-tune the HA.

However, HA fitting can be challenging in practice owing to variations in the degree of HL, best speech discrimination, and uncomfortable speech sound levels among individuals with hearing impairment. Even if the patient is subjectively satisfied with the HA after fitting, an objective evaluation such as a sound-field test may reveal incompatibility. Speech discrimination with HAs is sometimes better under normal speech sound levels and worse under loud speech levels than without HAs. In this study, we focused on cases where speech discrimination deteriorated when the speech sound level was raised and investigated the factors that contributed to this deterioration.

Corresponding author: Yoshihiro Nitta, e-mail: n-yoshihiro@med.kitasato-u.ac.jp
Received: April 21, 2024 • **Revision Requested:** August 11, 2024 • **Last Revision Received:** August 25, 2024 • **Accepted:** September 12, 2024 • **Publication Date:** November 25, 2024
Available online at www.advancedotology.org

METHODS

Patients

This retrospective study was approved by the appropriate Institutional Review Board (approval number: B22-078; date of approval: 2024/1/4). The need for informed consent was waived by posting an opt-out due to the retrospective nature of this study in accordance with Japanese ethical regulations. The participants were patients aged >20 years who underwent HA fitting and purchased the device at the outpatient clinic of the same hospital between January 2017 and December 2021. The HA fitting procedure was performed as follows.[2] The initial fitting was performed by having the patient wear a HA set up using a prescription formula (DSL ver. 5). After the patient wore the first fitted HA, we changed the amplifying characteristics according to feedback provided by the patients. At this point, hearing thresholds in the sound field were assessed to confirm the aided and functional gains (FGs). After the initial testing of the HA fitting, the gain, frequency response, and compression ratio were gradually adjusted. Before making the final decision to purchase a HA, the results of speech performance-intensity functions, aided thresholds, and FGs were confirmed. Although the evaluation of the tests was performed based on the guidelines for evaluating HA fitting,[1] we also noted the subjective evaluation by the patients. In addition, if the hearing thresholds in the sound field yielded insufficient results, we adjusted the HAs accordingly; however, we were unable to frequently correct them in a sufficient manner.

This retrospective observational study was based on the clinical records of participants. As a supplement, we excluded patients with an average hearing threshold ((500 Hz + 1000 Hz × 2 + 2000 Hz)/4) >90 decibels (dB) on pure-tone audiometry.

Speech Discrimination Test

The 67-S Japanese monosyllable word list was used for speech discrimination testing. Speech performance-intensity functions were measured at input levels of 65 and 80 dB of sound pressure level (dB SPL), with and without HAs. The experiments were conducted in a sound field according to the speech audiometry method described by the Japan Audiological Society.[3] Based on these results, we defined a sufficient benefit as that when HA fitting was satisfactory, that is, when the speech performance-intensity functions fulfilled any of the following criteria:[1]

1. When the HA was worn, the speech discrimination degree at 65 dB SPL improved by >15% from unaided hearing and did not deteriorate by >20% at 80 dB SPL from unaided hearing.
2. The degree of speech discrimination at 65 or 80 dB SPL was >75%. At each level, hearing did not deteriorate by >20% compared to that of the unaided ear when wearing the HA.

Furthermore, in order to focus on the cases where speech discrimination deteriorated when the speech sound level was raised, we defined an insufficient benefit as meeting the following criteria:

a. The ear did not fulfilll criterion 1) or 2).
b. Speech discrimination at 65 dB SPL was better with HAs than without HAs.
c. Speech discrimination at 80 dB SPL was worse with HAs than without HAs.

Comparison of Sufficient Benefit and Insufficient Benefit

Age, HA use, sex, pure-tone average, best speech intelligibility, type of HL, presence of acoustic reflex (AR), and recruitment were compared between sufficient benefit and insufficient benefit. Acoustic reflex testing was measured to assess the recruitment phenomenon. Acoustic reflex was considered positive if the reflex appeared with pure tone stimulation at 1 kHz up to 100 dB in the ipsilateral ear. In cases in which AR appeared, the recruitment phenomenon was measured by the difference between the hearing threshold at which AR appeared and the hearing threshold.

In addition, hearing thresholds in the sound field and speech discrimination without HAs, and hearing thresholds with HAs were compared between sufficient benefit and insufficient benefit. Moreover, the FG was obtained from the sound field thresholds, and half gain (1/2 G) and 1/3 gain (1/3 G) were calculated from the hearing thresholds of pure-tone audiogram at 250, 500, 1000, 2000, and 4000 Hz. Furthermore, a compression ratio of 50-80 dB SPL and the maximum output sound pressure setting for each frequency channel were examined from the recorded data of the HA fitting software.

Statistical Analysis

Analysis of variance was used to examine the survey items for sufficient benefit and insufficient benefit, and Bonferroni multiple comparison tests were used for post-hoc analyses. GraphPad Prism 8 (GraphPad Software Inc., La Jolla, CA, USA) was used for all statistical analyses. All data were presented as means and standard errors, and statistical significance was set at $P < .05$.

RESULTS

This study included 251 participants (96 men and 155 women; 296 ears) with a mean age of 67.3 (±17.3) years.

Speech Discrimination Test

Of the 296 ears, 229 ears that fulfilled criteria 1) or 2) were considered to have the sufficient benefit. There were 67 ears that did not fulfill either criterion 1) or 2). Of these 67 ears, 25 fulfilled target criteria b) and c), and these 25 ears were considered to have the insufficient benefit. All speech intelligibility results with and without HAs at 65 and 80 dBSPL in the insufficient benefit were shown (Figure 1).

Comparison of Sufficient Benefit and Insufficient Benefit

No significant differences were observed between sufficient benefit and insufficient benefit in terms of age, HA use, sex, pure-tone average, best speech intelligibility, type of HL, presence of acoustic reflex, or recruitment (Table 1).

First, hearing thresholds in the sound field and speech discrimination without HAs were compared between the sufficient benefit and insufficient benefit groups. The results showed insignificant differences in hearing thresholds and speech discrimination between the two groups ($P > .05$) (Figure 2). Hearing thresholds with HAs were significantly lower in the sufficient benefit group only at 4000 Hz, but there were no significant differences between the two groups at 250-1000 Hz (Supplementary Figure 1).

Moreover, the FGs were measured in the sufficient benefit and insufficient benefit groups and compared with their respective 1/2 G and 1/3 G. Functional gains of sufficient benefit were approximately 1/3 G at 500 and 4000 Hz and slightly larger at 1000 and 2000 Hz. By

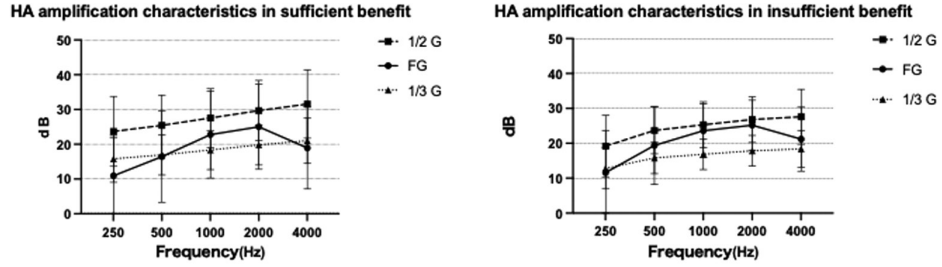


Figure 1. Change in speech discrimination at 65 and 80 dB SPL in insufficient benefit. The number of ears in the insufficient benefit group was 25. The left panel shows speech discrimination with and without HAs at 65 dB SPL, and the right panel shows speech discrimination with and without HAs at 80 dB SPL. Abbreviations: HAs, hearing aids; dB SPL, decibels of sound pressure level.

contrast, FGs of insufficient benefit were approximately 1/2 G at 1000 and 2000 Hz, smaller at 500 and 4000 Hz, and approximately 1/3 G at 250 Hz (Figure 3). Hearing thresholds in pure-tone audiogram were greater in the sufficient benefit compared to the insufficient benefit (Supplementary Figure 2), therefore 1/2 G and 1/3 G are higher in the sufficient benefit. However, mean hearing thresholds were not significantly different between the two groups ($P > .05$, Table 1). In addition, there were not significant differences in FG between the two groups ($P > .05$, Supplementary Figure 3). Furthermore, the difference between the 1/2 G and FG was calculated and compared between the ear categories. The difference was significantly larger in the sufficient benefit group than in the insufficient benefit group at 4000 Hz (Figure 4).

Finally, a compression ratio of 50-80 dB SPL and maximum output sound pressure settings for each frequency were examined for sufficient benefit and insufficient benefit. The results showed that the compression ratios at 2000 and 4000 Hz were significantly smaller in the insufficient benefit group than in the sufficient benefit group ($P < .05$) (Figure 5). No significant differences were observed in the respective maximum output sound pressures ($P < .05$).

DISCUSSION

Hearing aid fitting involves selecting a suitable HA for a person with HL and adjusting it accordingly. For linear HAs, the half-gain,[4] prescription of gain/output (POGO),[5] and National Acoustic Laboratories-Revised Profound methods have been used as the adjustment guidelines.[6] Patients with cochlear impairment may experience a reduced dynamic range, causing the perception of an exaggerated loudness owing to the recruitment phenomenon.[7] Therefore, non-linear HAs normalize loudness by adjusting the HA gain, ensuring that a patient with HL perceives the same loudness as a person with normal hearing.[8] The National Acoustic Laboratories-Non-Linear (NAL-NL)[9] and desired sensation level methods[10] are included in many HA-fitting software packages as specific selection methods for non-linear amplification. Hearing aid adjustments should be made by selecting the appropriate HA and prescription formula, followed by real-ear measurements, ensuring the adjustments are consistent with the prescription goals.[11] However, real-ear measurement is unpopular in Japan. Therefore, after selecting the appropriate HA and prescription formula in our outpatient clinic, we adjusted the HA by using sound field threshold

Table 1. Comparison of Sufficient Benefit and Insufficient Benefit

	Sufficient Benefit (n = 229)	Insufficient Benefit (n = 25)	*P*
Age (years)	65.8 ± 1.15	70.2 ± 3.48	.23[a]
HA wearing ear (Right/Left)	108/121	13/12	.67[b]
Pure-tone average	55.1 ± 0.98	52.65 ± 3.04	.43[a]
Sex (male/female)	87/142	11/14	.66[b]
Best speech intelligibility (%)	70.4 ± 1.51	65.2 ± 4.59	.27[a]
Type of HL (Sensorineural/Conductive/Mixed)	169/1/59	22/0/3	.23[b]
AR (+/–)	63/49	10/6	.78[b]
Recruitment (dB)	44.11 ± 1.25	42.5 ± 3.12	.63[a]

[a]T-test: $P > .05$.
[b]Fisher's exact test: $P > .05$.
Pure-tone average was measured from an average hearing threshold ((500 Hz + 1000 Hz × 2 + 2000 Hz)/4) >90 decibels (dB) on pure-tone audiometry.
Recruitment was measured as the difference between the hearing threshold at which the AR appeared and the hearing threshold at 1 kHz in the ear in which the AR appeared.
AR, acoustic reflex; HA, hearing aid; HL, hearing loss.

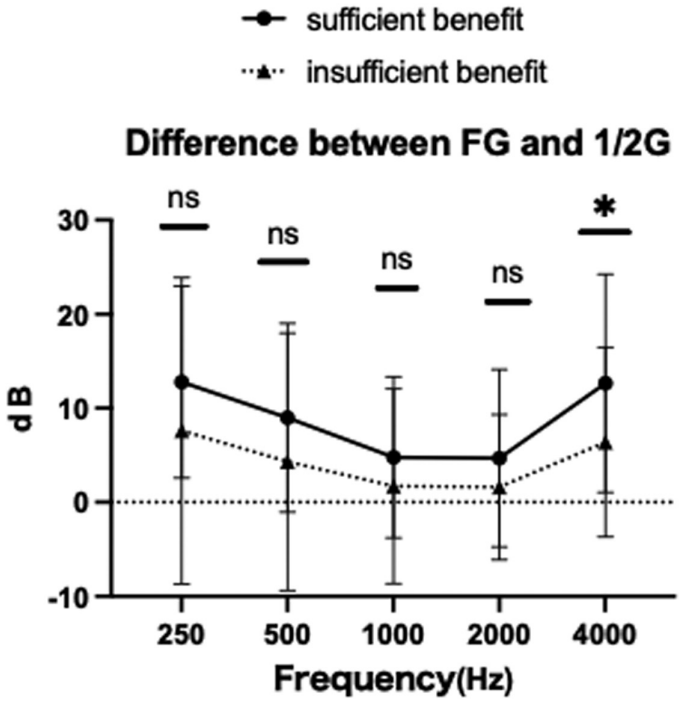


Figure 2. Hearing thresholds and speech discrimination without HAs for sufficient benefit and insufficient benefit. Hearing threshold and speech discrimination without HAs in the sound field for sufficient benefit (solid line) and insufficient benefit (wavy line) are indicated. No significant differences were observed between sufficient benefit and insufficient benefit groups in terms of hearing threshold and speech discrimination without HAs ($P > .05$). Abbreviations: HAs, hearing aids.

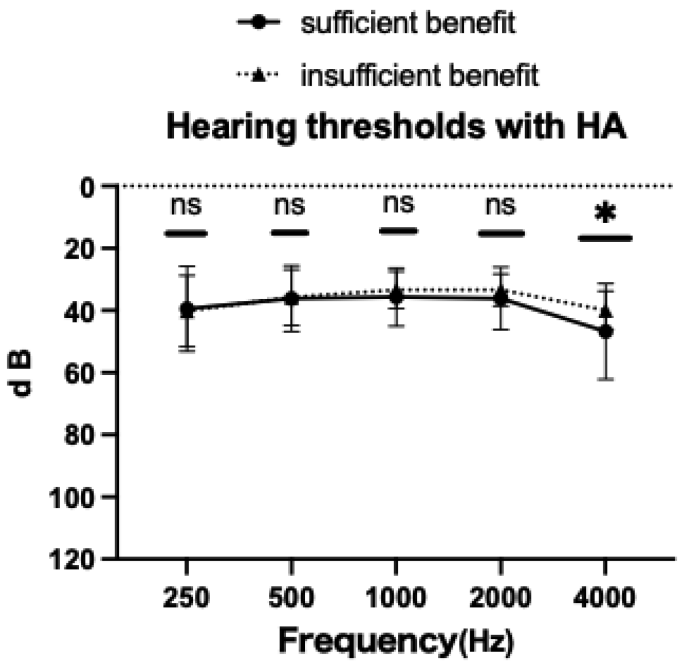


Figure 3. HA amplification characteristics in sufficient benefit and insufficient benefit. Circles, squares, and triangles indicate the average value of FG, half of the gain (1/2 G), and 1/3 gain (1/3 G), respectively, for each frequency. FGs of sufficient benefit were approximately 1/3 G at 500 and 4000 Hz and slightly larger at 1000 and 2000 Hz. FGs of insufficient benefit were approximately 1/2 G at 1000 and 2000 Hz and smaller at 500 and 4000 Hz. Abbreviations: HA, hearing aid; FG, functional gain.

measurement, as described in the 2010 guidelines for the evaluation of HA fitting.[1] During actual HA-fitting evaluations, speech discrimination sometimes improves at normal speech levels with HAs and deteriorates adversely at loud speech sounds. We investigated the cause of this phenomenon.

The insufficient benefit group had a larger FG overall than the sufficient benefit group (Figure 3), and the difference between 1/2 G and FG was significantly larger in the sufficient benefit group than in the insufficient benefit group at 4000 Hz (Figure 4). Examining the compression ratio of 50-80 dB SPL and the maximum output sound pressure setting for each frequency showed no differences in the maximum output sound pressure setting between sufficient benefit and insufficient benefit; however, a significant difference was observed in the compression ratio of 50-80 dB SPL at 2000 and 4000 Hz (Figure 5). HAs with wide dynamic range compression are adjusted to a compression ratio of 1.5-3[12]; however, the average compression ratio in the insufficient benefit group was approximately 1.1-1.2, which tended to be slightly lower than the standard.

Based on these results, an FG of approximately 1/2 G was considered excessive at 80 dB SPL input when the compression ratio was smaller than the standard value for patients with HL, except for those with severe HL. In fact, gain requirements for mild-to-moderate losses are reportedly better targeted with a 1/3 G rule rather than a 1/2 G rule.[13] For non-linear HAs, the gain varies with the input level, making them highly advantageous for real-ear measurements. However, in cases where real-ear measurements are difficult to perform or facilities for such measurements are unavailable, adjusting the HAs by using the FG is crucial. Moreover, because the hearing dynamic range is

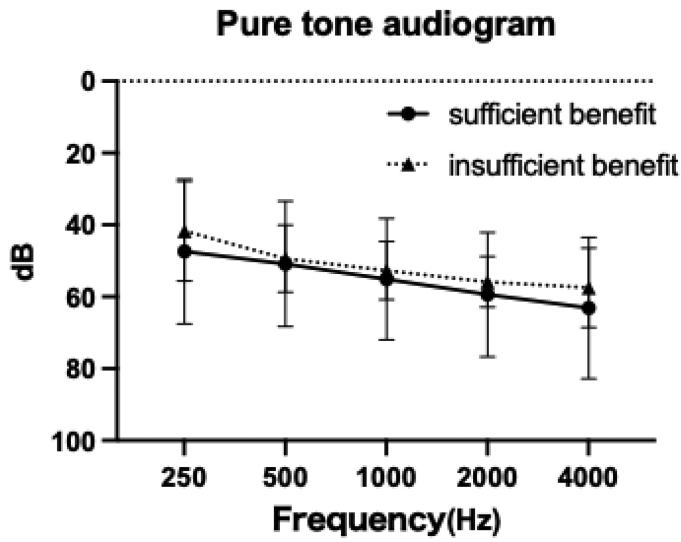


Figure 4. Difference between FG and 1/2 G for sufficient benefit and insufficient benefit. Circles (sufficient benefit) and triangles (insufficient benefit) show the difference between FG and 1/2 G. The difference was significantly larger in the sufficient benefit group than in the insufficient benefit group at 4000 Hz. Abbreviations: FG, functional gain; G, gain.

reduced in patients with sensorineural HL, compression is crucial for HAs, which reportedly improves speech intelligibility.[14,15,16] Therefore, adjusting the compression ratio is essential. Nevertheless, multichannel HAs with a compression ratio >3 will reduce speech discrimination with HAs in patients, even those with HL.[17]

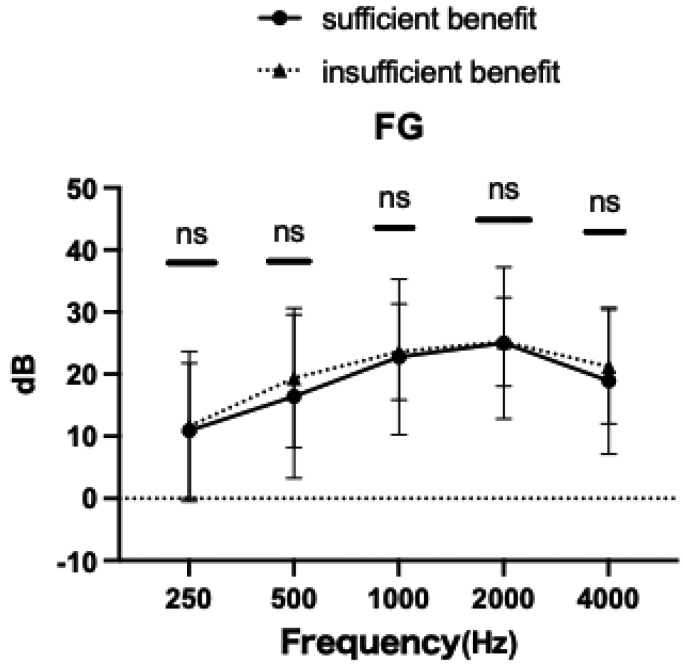


Figure 5. Compression ratio at 50-80 dB SPL and maximum output sound pressure in sufficient benefit and insufficient benefit. Circles (fully compliant ears) and triangles (inadequate ears) indicate the compression ratio at 50-80 dB SPL and maximum output sound pressure in sufficient benefit and insufficient benefit. The compression ratios at 2000 and 4000 Hz were significantly lower in the insufficient benefit group than in the insufficient benefit group. No differences were observed in the maximum output sound pressure between the sufficient benefit and insufficient benefit groups. Abbreviations: dB SPL, decibels of sound pressure level.

In this study, the compression ratio was adjusted to 1.2-1.7, and the FG was approximately 1/3 G in the sufficient benefit group, which showed an improvement in speech discrimination at 65 and 80 dB SPL with HAs. However, the compression ratio was lower than the standard value, and the FG was approximately 1/2 G in the insufficient benefit group, which showed a deterioration in speech discrimination at 80 dB SPL with HA. One possible reason for such an HA setting in the insufficient benefit group is that the gain was increased without changing the compression ratio to improve speech intelligibility under HA use. The degree of gain to which HA fitting should be adjusted according to the degree of HL is unclear, and further prospective research is needed to determine whether adjusting to the average value of sufficient benefit will improve speech intelligibility. However, as a solution for patients with deteriorating speech discrimination at 80 dB SPL with HAs, one might try changing the compression ratio to about 1.5 at 50-80 dB SPL and the FG to about 1/3 G.

Despite the insights that were provided in this study, several limitations must be acknowledged. First, this study was a retrospective analysis of speech discrimination tests at the time of the HA purchase decision. Second, we continued to adjust the HAs despite the insufficient results obtained in this test. However, there are many cases in which sufficient adjustment or evaluation has not been implemented. Therefore, it was not possible to verify in this retrospective observational study whether insufficient benefits can be improved by adjusting the compression ratio and FG to 1.5 and 1/3G, respectively. Thus, our future interventional study aims at investigating whether such an approach in the initial setting would provide sufficient HA adjustment.

In conclusion, in terms of gain, larger FGs were obtained in the insufficient benefit group than in the sufficient benefit group. The compression ratios at 50-80 dB SPL tended to be lower than the standard values in the insufficient benefit group. This study revealed that adjusting the compression ratio and lowering the FG to approximately 1.5 and 1/3 G, respectively, may help in improving speech discrimination if it worsens with increasing sound levels during HA fitting; however, the suitability of this adjustment needs to be verified in future studies.

Ethics Committee Approval: This study was approved by Ethics Committee of Kitasato University (Approval No.: B22-078, Date: January 4, 2024).

Informed Consent: The need for informed consent was waived by posting an opt-out due to the retrospective nature of this study in accordance with Japanese ethical regulations.

Peer-review: Externally peer-reviewed.

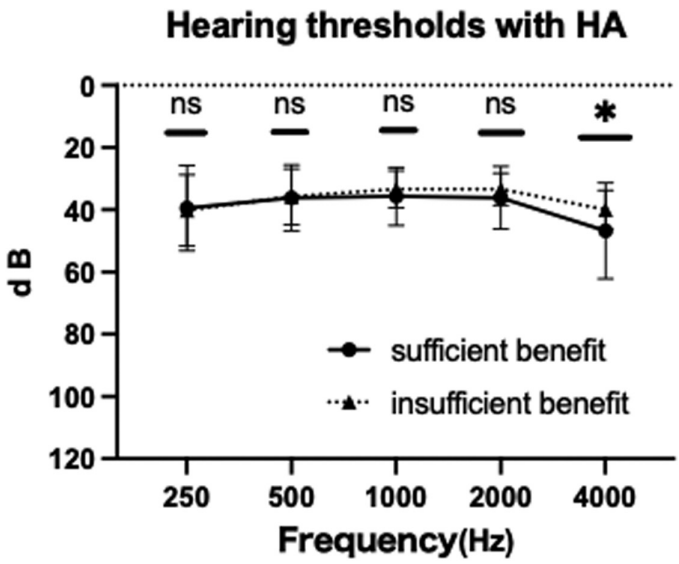
Author Contributions: Concept – Y.N., H.S.; Design – Y.N., H.S.; Supervision – T.Y.; Resource – Y.N.; Materials – Y.N.; Data Collection and/or Processing – Y.N., S.F., S.U., Y.H.; Analysis and/or Interpretation – Y.N., H.S.; Literature Search – Y.N., H.S.; Writing – Y.N., H.S.; Critical Reviews – T.Y.

Declaration of Interests: The authors have no conflict of interest to declare.

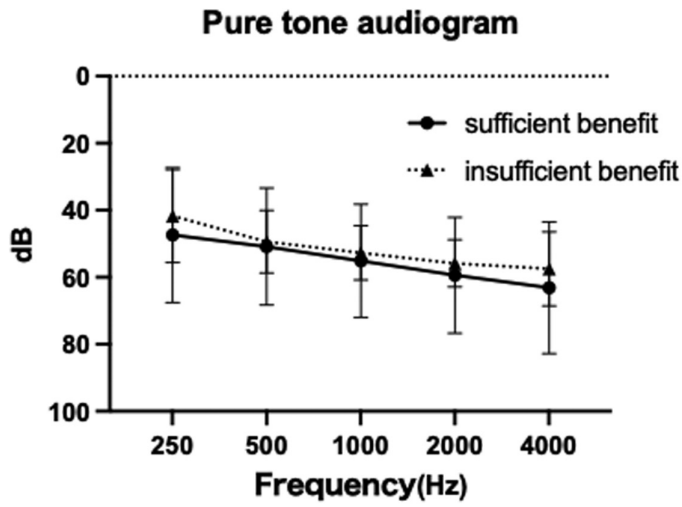
Funding: The authors declared that this study has received no financial support.

REFERENCES

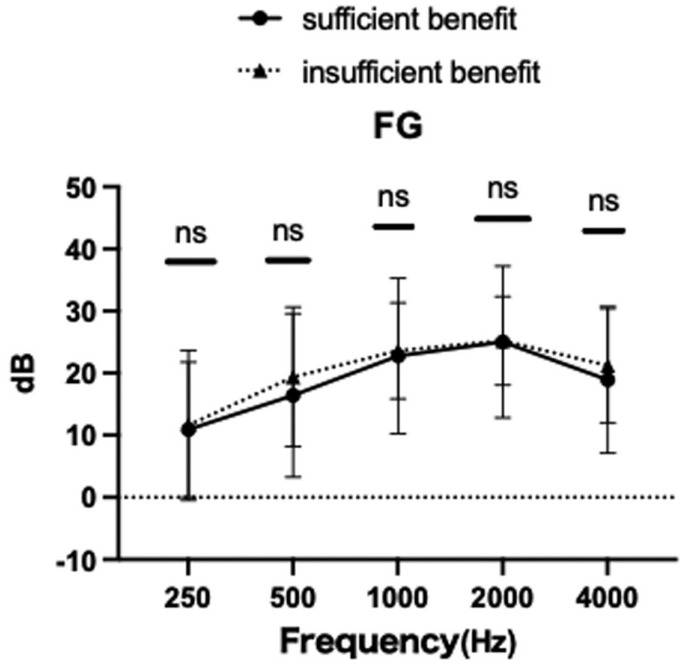
1. Kodera K, Hosoi H, Okamoto M, et al. Guidelines for the evaluation of hearing aid fitting (2010). *Auris Nasus Larynx*. 2016;43(3):217-228. [CrossRef]
2. Furuki S, Sano H, Kurioka T, et al. Comparison of real-ear insertion gains in Japanese-speaking individuals wearing hearing aids with DSLv5 and NAL-NL2. *Auris Nasus Larynx*. 2021;48(1):75-81. [CrossRef]
3. Yamashita K, Matsuhira T. Speech audiometry. *Audiol Jpn*. 2008;51(3): 167-176.
4. Lybarger SUS Patent application SN, 532; 1944:278.
5. Thorpe S, Jardine C. The efficacy of the Prescription of Gain/Output (POGO) in fitting hearing aids to mild and moderate sensorineural hearing losses. *S Afr J Commun Disord*. 1994;41:65-72.
6. Byrne D, Parkinson A, Newall P. Chapter 25. Modified hearing aid selection procedures for severe/profound hearing losses. In: Studebaker GA, Bess FH, Beck LB, eds. *The Vanderbilt Hearing-Aid Report II*. Parkton, MD: York Press; 1991:295-300.
7. Hellman RP. Cross-modality matching: a tool for measuring loudness in sensorineural impairment. *Ear Hear*. 1999;20(3):193-213. [CrossRef]
8. Dillon H. 6 Compression systems in hearing aids. In: *Hearing Aids*. 2nd ed New York: Thieme; 2012:170-197.
9. Keidser G, Dillon H, Flax M, Ching T, Brewer S. The NAL-NL2 prescription procedure. *Audiol Res*. 2011;1(1):e24. [CrossRef]
10. Scollie S, Seewald R, Cornelisse L, et al. The desired sensation level multistage input/output algorithm. *Trends Amplif*. 2005;9(4):159-197. [CrossRef]
11. Dillon H. 11 Selecting, adjusting and verifying hearing aids. In: *Hearing Aids*. 2nd ed New York: Thieme; 2012:336-354.
12. Dillon H. Static compression characteristics. In: *Hearing Aids*. 2nd ed New York: Thieme; 2012:175-176.
13. Killion MC. The three types of sensorineural hearing loss: loudness and intelligibility considerations. *Hear J*. 1993;46(11):31-36.
14. Davies-Venn E, Souza P, Brennan M, Stecker GC. Effects of audibility and multichannel wide dynamic range compression on consonant recognition for listeners with severe hearing loss. *Ear Hear*. 2009;30(5):494-504. [CrossRef]
15. Humes LE, Christensen L, Thomas T, Bess FH, Hedley-Williams A, Bentler R. A comparison of the aided performance and benefit provided by a linear and a two-channel wide dynamic range compression hearing aid. *J Speech Lang Hear Res*. 1999;42(1):65-79. [CrossRef]
16. Jenstad LM, Seewald RC, Cornelisse LE, Shantz J. Comparison of linear gain and wide dynamic range compression hearing aid circuits: aided speech perception measures. *Ear Hear*. 1999;20(2):117-126. [CrossRef]
17. Bustamante DK, Braida LD. Multiband compression limiting for hearing-impaired listeners. *J Rehabil Res Dev*. 1987;24(4):149-160.



Supplementary Figure 1. Hearing thresholds with HAs were compared for sufficient benefit to insufficient benefit. Abbreviations: HAs, hearing aids.



Supplementary Figure 2. Pure tone audiogram in the sufficient benefit and insufficient benefit.



Supplementary Figure 3. Functional gains in the sufficient benefit and insufficient benefit.