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ORIGINAL RESEARCH

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Sound localization in patients with a unilateral hearing aid: Discordance between the right and left ears

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Abstract

Objectives: Patients with unilateral hearing loss (UHL) have difficulty in recognizing the direction of a sound. Previous studies have shown that hearing aids (HAs) could improve the directional perception of sound. In this study, we analyzed the results of sound localization tests in patients using a unilateral HA.

Methods: All patients with UHL who had performed sound localization tests since 2018 were included in this study. Sound localization tests, functional gain tests, and the speech discrimination scores (SDSs) were analyzed. The tests were obtained at 1-, 3-, and 6-month after fitting the HA.

Results: Of the 32 patients with UHL, 13 were right-sided and 19 were left-sided. After 6 months of using a HA, the results of the sound localization test were significantly better in patients with right than left UHL (percent correct [PCT], 61.9 ± 24.0% vs. 37.9 ± 24.6%, $p = .011$; mean absolute error (MAE), 41.4 ± 23.9° vs. 65.5 ± 28.6°, $p = .018$; root-mean-square error (RMS), 25.8 ± 17.6° vs. 48.8 ± 24.5°, $p = .007$]. The aided SDSs were not different between the two groups (78.7 ± 16.5% vs. 77.2 ± 18.5%, $p = .825$).

Conclusion: The side of the hearing loss could have a substantial effect on sound localization in UHL patients using a HA. Sound localization test results should be interpreted with the consideration of this discordance.

Level of Evidence: 4

KEYWORDS

sound localization, unilateral hearing aid, unilateral hearing loss

1 | INTRODUCTION

The prevalence of adult unilateral hearing loss (UHL) was estimated to be about 5.55% in the United States (US).[1] To improve decreased hearing ability, the use of a hearing aid (HA) for mild to moderate UHL and cochlear implantation (CI) for severe to profound UHL has been suggested. Satisfaction with UHL management varied widely, and the outcomes were not consistent.[2–6] Moreover, there have been few detailed studies on the use of HAs in UHL because the rate of HA use is only 1.56% in UHL.[1]

Therefore, in the clinical setting, it is still difficult to determine the most appropriate hearing rehabilitation methods for patients with UHL. Although authors have often suggested HA use for patients with mild to moderate UHL to improve sound localization, there was no clear evidence of the effectiveness in the improvement of sound

Jungho Ha and Hantai Kim contributed equally to this study.

localization. The aim of the study was to find out whether HA use could improve sound localization in patients with UHL and to investigate whether the side of hearing loss could affect the results of the sound localization tests.

2 | MATERIALS AND METHODS

2.1 | Subjects

This study was approved by the Institutional Review Board of Ajou University Hospital (AJIRB-DEV-DE1-17-227). Signed informed consent was obtained from all subjects before the use of a HA. All patients with UHL who had performed sound localization tests at our hospital since 2018 were included in this study. Patients who underwent CI for severe to profound UHL, and those using a rerouting HA, were excluded. All subjects had an average pure-tone threshold of <25 dB in the contralateral ear and were successfully followed up for at least 6 months.

Finally, 32 patients (13 with right UHL and 19 with left UHL) were enrolled in the study. Sex, age, duration of hearing loss, and the types of an HA were also investigated. Evaluations including pure-tone audiometry, speech discrimination scores (SDSs), and sound localization tests with a HA were performed after 1, 3, and 6 months of HA use.

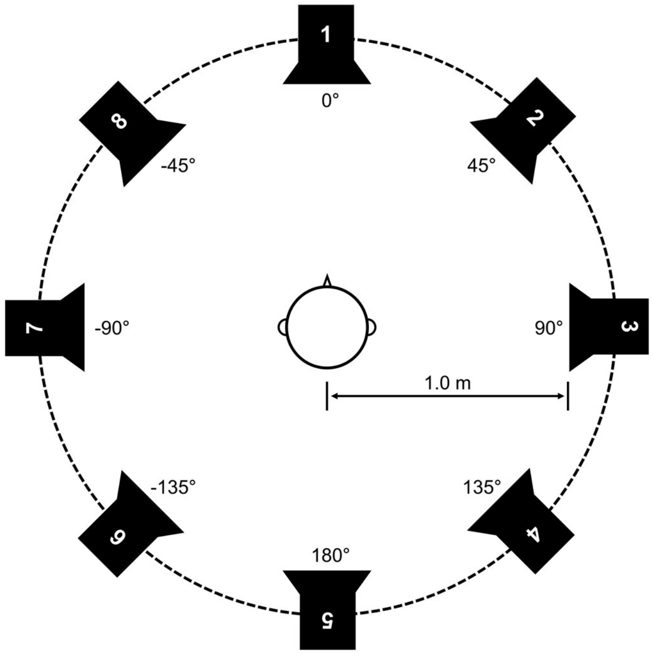

FIGURE 1 Loudspeaker setup for the sound localization test. The test was conducted in a soundproof room with eight loudspeakers equally distributed at a height of 1.2 m in a circle with a radius of 1.0 m. The angle between any two adjacent speakers was 45°

2.2 | Sound localization test

The sound localization test was performed using the setup illustrated in Figure 1. The test was conducted in a sound-proof room with eight loudspeakers (HS50M, Yamaha Corporation) equally distributed at a height of 1.2 m in a circle with a radius of 1.0 m. The angle between any two adjacent loudspeakers was 45°. White noise was randomly emitted randomly from each loudspeaker (Protea™ NE Software 5.23, Ashly Audio, Inc.). The eight loudspeakers generated the stimuli three times each in a random order, so there were 24 trials for each patient. Each patient entered their responses on a keypad while looking straight ahead at the front loudspeaker (#1). After the sound presentation, the patient pushed the number corresponding to the loudspeaker emitting the sound.

The following sound localization measurements were calculated: percent correct (PCT), mean absolute error (MAE; average angle difference between the actual sound-emitting speaker and the speaker indicated by the patient), and the root-mean-square (RMS; calculated by the following equation):

$$\text{RMS} = \sqrt{\sum_{i=1}^{n} \frac{(\text{Angle difference})_i^2}{n}}$$

2.3 | Statistical analysis

The independent *t*-test and chi-squared test were used as appropriate between the right and left UHL groups. The Wilcoxon signed-rank test was applied to identify the significance between unaided status and 1, 3, or 6 months of using a HA. Multiple linear regression was used for multivariate analysis of the MAE and RMS. All variables were included in the initial regression model but variables that were not significant were excluded (via stepwise selection). Statistical analyses were performed using IBM SPSS Statistics for Windows (version 23.0; IBM Corp., Armonk, NY, USA). In all analyses, $p < .05$ was considered statistically significant.

3 | RESULTS

The 32 patients included in the study consisted of 13 with right UHL and 19 with left UHL. The age at the start of HA use was 52.3 ± 14.2 and 47.9 ± 18.2 years in the right and left UHL groups, respectively. Most of the subjects reported duration of hearing loss of <5 years (92.3% in the right UHL group and 89.5% in the left UHL group). The pure-tone thresholds and SDSs were not significantly different between the two groups (Table 1).

After 1 month of HA use, SDS increased to 75% in both the right and left UHL groups and remained similar at 6 months. The PCT showed a tendency to decrease until 3-month after HA use. However, the tendency was not statistically significant ($p = .080$ in the right UHL group and $p = .360$ in the left UHL group). At 6 months, the PCT decreased in the left UHL group (from 52.2 ± 24.7% unaided to 37.9 ± 24.6% with a left HA), while the right UHL group showed recovery to the unaided level (from 60.3 ± 25.6% unaided to 61.9 ± 24.0% with a right HA) (Figure 2).

TABLE 1 Basic demographics of the subjects

	Right UHL ($n = 13$)	Left UHL ($n = 19$)	*p*-value
Age (years)	52.3 ± 14.2	47.9 ± 18.2	.469[a]
Sex			.072[b]
Male	9 (69.2%)	7 (36.8%)	
Female	4 (30.8%)	12 (63.2%)	
Period of hearing loss			.683[b]
< 5 years	12 (92.3%)	17 (89.5%)	
6–10 years	0 (0.0%)	1 (5.3%)	
> 10 years	1 (7.7%)	1 (5.3%)	
Hearing aid type			.273[b]
Completely-in-canal	8 (61.5%)	9 (47.4%)	
Receiver-in-canal	4 (30.8%)	10 (52.6%)	
In-the-canal	1 (7.7%)	0 (0.0%)	
UHL ear			
Unaided pure-tone AC thresholds (dB)	59.1 ± 10.9	61.5 ± 12.8	.586[a]
Unaided SDS (%)	48.8 ± 22.2	48.8 ± 29.8	.998[a]
Contralateral hearing (normal ear)			
Unaided pure-tone AC thresholds (dB)	14.9 ± 8.0	15.9 ± 8.6	.756[a]
Unaided SDS (%)	97.5 ± 4.5	98.3 ± 3.1	.593[a]

Abbreviations: AC, air conduction; BC, bone conduction; SDS, speech discrimination score; UHL, unilateral hearing loss.
[a]Independent *t*-test.
[b]Chi-square test.

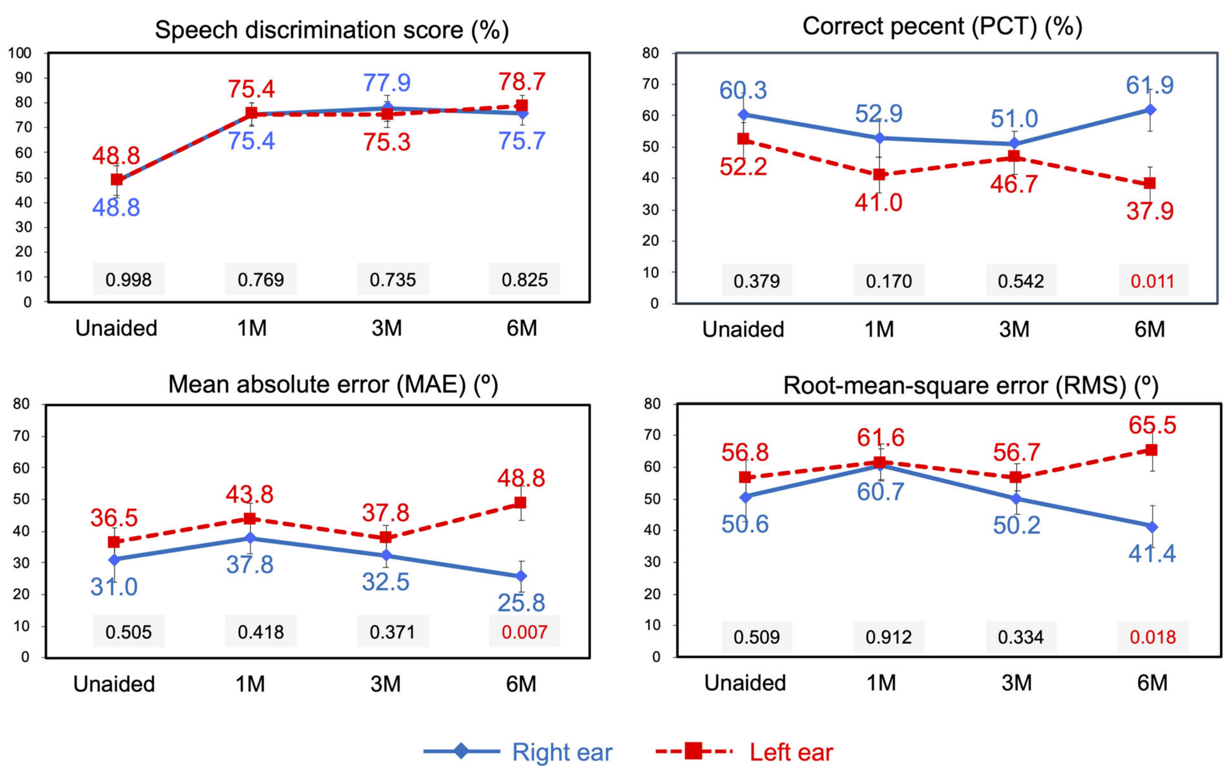

FIGURE 2 Longitudinal changes in speech discrimination scores and the results of the sound localization test after 6 months

TABLE 2 Factors affecting MAE and RMS at 6 months (multiple linear regression)

	MAE ($R^2 = 0.533$)			RMS ($R^2 = 0.517$)		
	B	95% confidence interval	*p*-value	*B*	95% confidence interval	*p*-value
Hearing loss ear (left)	20.881	7.778–33.984	.003	20.877	5.138–36.615	.011
Unaided SDS in UHL ear	−0.338	−0.587 to −0.089	.010	−0.367	−0.661 to −0.072	.016
Unaided MAE	0.392	0.095 to 0.689	.012			
Unaided RMS				0.520	0.210 to 0.829	.002

Note: Age, gender, hearing aid type (completely-in-canal), aided SDS on UHL ear at 6 months, unaided pure-tone threshold average on UHL ear, SDS on normal ear, pure-tone threshold average on normal ear were also included as variables; however, they were excluded by the stepwise selection.
Abbreviations: MAE, mean absolute error; RMS, root-mean-square error; SDS, speech discrimination score; UHL, unilateral hearing loss.

The MAE in the right UHL patients was 31.0 ± 26.1° unaided, and it was 37.8 ± 18.0° at 1 month ($p = .091$). Then, it reached to 25.8 ± 17.6° at 6 months ($p = .574$). However, in the left UHL patients, the MAE even became even worse at 6 months compared to unaided patients (36.5 ± 20.0° unaided to 48.8 ± 24.5° at 6 months, $p = .033$). The group difference at 6 months between the right and left UHL was statistically significant ($p = .007$). The RMS showed a similar pattern. In right UHL, the RMS was 50.6 ± 28.5° unaided, and it became 60.7 ± 18.0° at 1 month ($p = .116$). It reached 41.4 ± 23.9° at 6 months ($p = .196$). In contrast, the RMS in left UHL patients tended to be worse at 6 months (56.8 ± 23.6° unaided to 65.5 ± 28.6° at 6 months). This tendency was not significant ($p = .227$); however, a gap between the groups was noticeable (41.4 ± 23.9° in right vs. 65.5 ± 28.6° in left UHL patients, $p = .018$) (Figure 2).

As other factors may have affected the results, a multivariate analysis was performed. All variables, including age, sex, the type of a HA, the unaided pure-tone threshold, SDS in the ear with UHL, pure-tone thresholds and SDS in the ear with normal hearing, the side of UHL, and the unaided MAE and RMS, were included in the multiple linear regression analysis. Finally, the side of UHL, unaided SDS in the UHL ear, and unaided MAE and RMS were included in the final regression model. The other variables were excluded via stepwise selection. Both the MAE and RMS were estimated to be about 20° higher in the left than in the right UHL group (Table 2).

4 | DISCUSSION

Binaural hearing, enabled by the squelch effect, binaural summation, and the head shadow effect, is important for sound localization and understanding of speech in noise.[7–10] Therefore, it can be assumed that UHL patients with loss of hearing function in one ear would have difficulties with sound localization. In fact, UHL patients have reported feeling discomfort in almost all listening and communication situations, with specific difficulties experienced with respect to localization and the awareness of sound coming from the UHL side.[11,12]

As an increase in the hearing function of the UHL ear may alleviate these difficulties, we have often suggested a HA for UHL patients. However, the effects of HA use are somewhat inconsistent. In this study, patients with the right UHL using the right HA had better performance on the sound localization tests. The authors would like to investigate whether this discordance in performance between right and left UHL patients still occurred when the effects of other variables were controlled. The results showed that the right UHL group had better performance in terms of sound localization. Right UHL patients with right HA showed improved sound localization after 6 months of steady HA use. In contrast, the results of the sound localization test varied among the left UHL patients with a left HA.

A previous study reported discordance in HA performance between patients with right and left UHL. Mondelli et al. studied the efficacy of HA in UHL patients and showed that patients with right UHL tended to have better sound localization, temporal ordering, and resolution performance than those with left UHL.[6] Other studies have also shown differences in temporal resolution between patients with left and right UHL. Particularly, in the evaluation of temporal resolution using the random gap detection test, patients with UHL in the right ear showed better results.[13,14] The studies suggested that this was because the left hemisphere of the brain is responsible for temporal resolution.[13,14]

Auditory stimuli received by the right ear pass through the cochlea to the cochlear nucleus and then ascend along both sides of the medulla oblongata. The cochlear nucleus on the right side delivers about 70%–90% of the total stimuli to the left superior olivary complex, with the remaining 10%–30% of the stimuli going to the right superior olivary complex, then ascends to the brain. The left hemisphere is related to speech function, and the left primary auditory cortex plays a dominant role in the temporal aspect of auditory stimuli.[15,16] Therefore, sound stimuli coming through the right ear may be more advantageous for auditory functions, including sound localization. The results of this study can be considered in this context.

Neural plasticity in the brain allows for central reorganization. Increased auditory stimuli can also prompt reorganization. For example, a patient's tinnitus was relieved following CI and the introduction of new auditory stimuli through the implant. This phenomenon can be explained by the central reorganization of the brain.[17] In this study, although patients with left HA showed poor sound localization performance, the localization function may be improved by reorganization over a longer follow-up period. Moreover, most of the subjects in this study reported a period of hearing loss of 1–5 years, so the duration of sound deprivation was relatively short. Patients with longer-duration hearing loss may show different results due to central reorganization associated with a longer period of sound deprivation.

Bone conduction HAs such as the Bone Anchored Hearing Aid (BAHA®) or the Bonebridge® and CI may be chosen for unilateral hearing loss. Some studies reported changes in sound localization in bone conduction HAs and CIs. CIs showed better outcomes than bone conduction HAs in sound localization, even though a CI needs quite a long time to improve sound localization.[18,19] However, the discordance between right and left ears was not investigated in those studies. Therefore, in a future study, it would be necessary to determine if such discordance also occurs in patients with CIs or bone conduction HAs.

5 | CONCLUSION

With the use of HA, aided SDSs and other audiometric results seemed to show similar improvements between right and left UHL patients. However, the side of UHL could have an effect on sound localization. Therefore, the results of the sound localization test should be interpreted with the consideration of this discordance between the right and left UHL.

CONFLICT OF INTEREST

The authors have no conflict of interests to declare.

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