ORIGINAL

Effects of FM system fitted into normal hearing ear on speech-in-noise recognition in Japanese school-aged children with unilateral severe-to-profound hearing loss

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Abstract : Objectives : We examined speech recognition ability of elementary school-aged Japanese children with unilateral hearing loss under noisy environments and then examined the effects of the FM system fitted into their normal hearing ear on their speech recognition ability. Methods : Twelve children with severe-to-profound sensorineural hearing loss and ten age-matched children with bilateral normal hearing received speech recognition test in quiet and noisy environments. Other nine children with severe-to-profound sensorineural hearing loss received speech recognition test with or without the FM receiver fitted to the normal hearing ear in quiet and noisy environments. Results : Signal-to-noise ratio (SNR) in Japanese elementary school classrooms was estimated to be -6.9 dB at a preferential seat. In noisy environment of -5 dB SNR similar to working classrooms, the correct rates of speech recognition test in children with unilateral hearing loss were significantly lower, compared with those in children with bilateral normal hearing. In the noisy environment, the correct rates in children aided by the FM system with unilateral hearing loss were significantly better, compared with unaided ones. Conclusion : The results suggested that the FM system is recommended as an audiological management for improvement of speech recognition of children with unilateral hearing loss in noisy classrooms. J. Med. Invest. 65 : 216-220, August, 2018

***Keywords* :** *children with unilateral hearing loss, speech recognition, noisy environment, classroom, FM system*

INTRODUCTION

Until recently, it was believed that unilateral hearing loss has little impact on a child's speech-language development. However, there is growing evidence that children with unilateral hearing loss have speech and language delays and impaired speech recognition in noise (1, 2, 3). Recently it was reported that school-aged children with unilateral hearing loss showed worse oral language scores than those of their siblings with normal hearing (4). Since such listening problems could lead to difficulties in following classroom instructions and discussions, unilaterally hearing impaired children may have a risk for academic failure (5, 6). Therefore, it is necessary to clarify speech recognition ability of children with unilateral hearing loss and compare it with that of children with bilateral normal hearing under noisy environments like a classroom setting.

Nowadays, the primary educational recommendation for children with unilateral hearing loss is preferential classroom seating at a minimum distance from the teacher with the normal hearing ear oriented towards the teacher. When audiological management approach is recommended, a contralateral routing of signals (CROS)-type hearing aid is sometimes suggested to offer some benefit for children with unilateral hearing loss. However, a previous study reported that the device might worsen speech recognition in noisy environments (7).

An alternative audiological approach to classroom management is the "FM system", a personal assistive device that is used as school-based intervention for children with hearing loss. The teacher wears a microphone, and the receiver is applied to the child's normal ear, so that the student can directly hear the teacher's voice. It was reported that regardless of the listening environment, the FM system improved speech recognition in individual children with unilateral hearing loss, compared with CROS (8). However, it is necessary to clarify whether the FM system improves speech recognition ability of children with unilateral hearing loss under noisy environments like a classroom setting.

In the present study, we examined speech recognition ability of elementary school-aged Japanese children with unilateral severe-to-profound sensorineural hearing loss under noisy environments and compared it with that of age-matched children with bilateral normal hearing. Moreover, we examined the effects of the FM system fitted into the normal hearing ear of children with unilateral hearing loss on improvement of their speech recognition ability under noisy environments similar to working elementary school classrooms in Japan.

PATIENTS AND METHODS

Patients

Both male and female elementary school-aged Japanese children were enrolled in the present study. Inclusion criteria : children were eligible if they could both pure-tone audiometry and speech recognition test securely. Exclusion criteria : children were excluded

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if they had complications other than hearing loss, such as Down syndrome.

The first group was made of twelve children with unilateral severe-to-profound sensorineural hearing loss defined as a pure tone average hearing level of more than 70 dB in one ear and normal hearing defined as a pure tone average hearing level of less than 25 dB in the opposite ear (4 males and 8 females, mean age : 7.7 ± 1.2 years old). The second group was made of ten age-matched children with bilateral normal hearing defined as a pure tone average hearing level of less than 25 dB in both ear as a control (5 males and 5 females, mean age : 8.1 ± 1.9 years old). They received speech recognition test in both quiet and noisy environments.

The third group was made of nine children with unilateral severe-to-profound sensorineural hearing loss, who were fitted with a FM receiver into the normal hearing ear (4 males and 5 females, mean age : 8.6 ± 1.8 years old). They received speech recognition test with or without a FM receiver in both quiet and noisy environments.

The cause of unilateral severe-to-profound sensorineural hearing loss was unknown with the onset in early childhood in both first and third groups of children. No children had a diagnosis of mental retardation in all three groups.

The present study was approved by the Committee for Medical Ethics of Tokushima University Hospital, and a written informed consent was obtained from a parent of each child prior to the study.

Speech recognition test in noise

Speech recognition test in a sound field was performed in the audiometric test room of our otolaryngology clinic and correct rates of speech recognition were measured according to the guidelines for the evaluation of hearing aid fitting (2010) published by Japan Audiological Society (9). Japanese monosyllables from the 57-S word list made by Japan Audiological Society was used as the speech material (10). Each monosyllable was presented at 50 dB time-averaged SPL (sound pressure level) from a loudspeaker placed in front of a subject sitting at a distance of 80 cm in quiet environment. It was then presentedin noise environments of 0 dB and -5 dB signal-to-noise ratio (SNR), where white noise (WN) was presented at 50 and 55 dB SPL from another loudspeaker placed behind the subject at a distance of 80 cm (Fig. 1A). Children were instructed to look at a soft toy on the front loudspeaker to avoid their head rotation during speech recognition test.

Speech recognition test in noise with FM system

The FM system used in the present study consisted of a radio transmitter with a microphone (Inspiro FM transmitter, Phonak Inc., Switzerland) and an open-fit FM receiver (iSense micro FM reciever, Phonak Inc., Switzerland). In the audiometric test room, the radio transmitter was placed at a distance of 20 cm in front of the loudspeaker facing subjects who were fitted with a FM receiver into the normal hearing ear, because in a classroom, the transmitter is hanging on theteacher's neck at a distance of 20 cm from the mouth. Japanese monosyllables from the 57-S word list were presented at 50 dB time-averaged SPL from the front loudspeaker facing a subject sitting at a distance of 80 cm in quiet environment. It was then presented in noisy environments of 0 dB and -5 dB SNR, where WN was presented at 50 and 55 dB SPL from another loudspeaker placed behind the subject at a distance of 80 cm (Fig. 1B). Children were instructed to look at a soft toy on the front loudspeaker to avoid their head rotation during speech recognition test.

Noise sound ratio in classroom

Although data logging system in the hearing aid varies considerably across hearing aid manufacturers, it keeps track of the duration of hearing aid usage and the characteristics listening environments, such as quiet, speech, speech in noise and noise only (11). The data logging system in Oticon's Epoq XW hearing aid (Denmark) can track sound pressure levels of self-speech and ambient noise (12). In a preliminary study, five volunteers wore open-fit Oticon's Epoq XW hearing aid on the auricle without gain, and pronounced like a teacher in a quiet classroom. The sound pressure levels of self-speech obtained by the data logging system of the hearing aid was virtually equivalent to those measured by a sound level meter placed at a distance of 30 cm in front (data not shown). In Japanese elementary school classrooms, a typical preferred seating location for children with unilateral hearing loss is at a distance of 120 cm from the teacher. Theoretically, the sound decay is obtained by the following formula :$-20 \times \log_{10}$ (A/B), where A is 0.3 m and B is 1.2 m. Therefore, the sound levels of teacher's talk obtained by the data logging system will be attenuated with $-20 \times \log10 (0.3/1.2) = -12.0$ dB at the preferred seats in Japanese elementary school classrooms. In the present study, averaged ambient noise levels in classrooms of six elementary schools in Tokushima prefecture of Japan and averaged speech levels of a teacher's talk for 50 min in each classroom were measured using the data logging system of open-fit Oticon's Epoq XW hearing aid on teacher's auricle without gain.

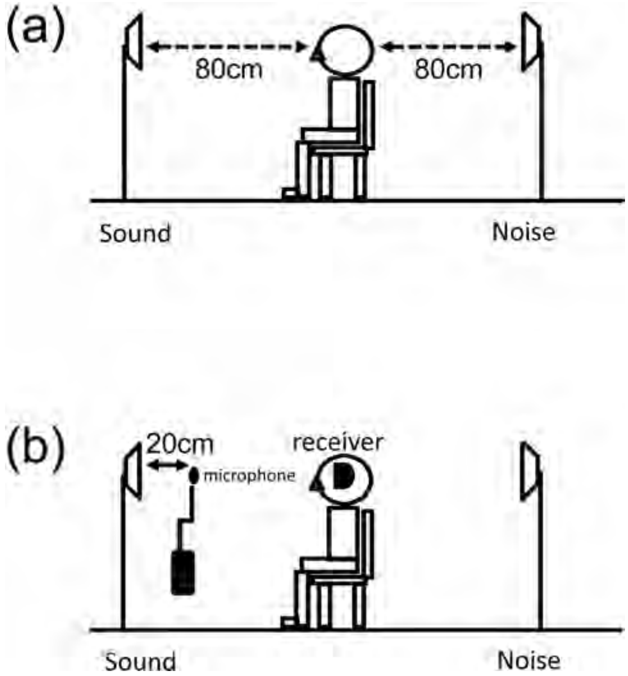

Fig. 1 a, b
Speech recognition test in noise without (a) and with (b) FM system. Japanese monosyllables were presented at 50 dB time-average SPL from the front loudspeaker and a white noise was presented at 50 or 55 dB SPL from the rear loudspeaker.

Statistical analysis

Statistical analysis was done using two-factor factorial analysis of variance and one factor analysis of variance with Scheffe's F post-hock test (Statcel version 3, OMS Publishing Inc, Saitama, Japan). $p < 0.05$ was considered statistically significant.

RESULTS

In the children with bilateral normal hearing, the correct rates of speech recognition test were 89.8 ± 3.8% (n=10) in quiet, 78.8 ± 4.2% (n=10) and 70.4 ± 6.4% (n=10) in noisy environments of 50 and 55 dB WN, respectively. Thus, the correct rates of speech recognition test were significantly decreased in noisy environments of 0 and 5 dB SNR, compared with those in quiet environment in normal hearing children ($p < 0.05$). In the children with unilateral severe-to-profound hearing loss, the correct rates of speech recognition test were 87.3 ± 5.5% (n=12) in quiet, 70.7 ± 6.6% (n=12) and 57.3 ± 8.8% (n=9) in noisy environments of 50 and 55 dB WN, respectively. Thus, the correct rates of speech recognition test were also significantly decreased in noisy environments of 0 and -5 dB SNR, compared with those in quiet environment in unilateral hearing deficit children ($p < 0.05$). However, in noisy environment of 55 dB WN (-5 dB SNR), the correct rates of speech recognition test in children with unilateral hearing loss were significantly decreased, compared those in children with bilateral normal hearing ($p < 0.05$) (Fig. 2).

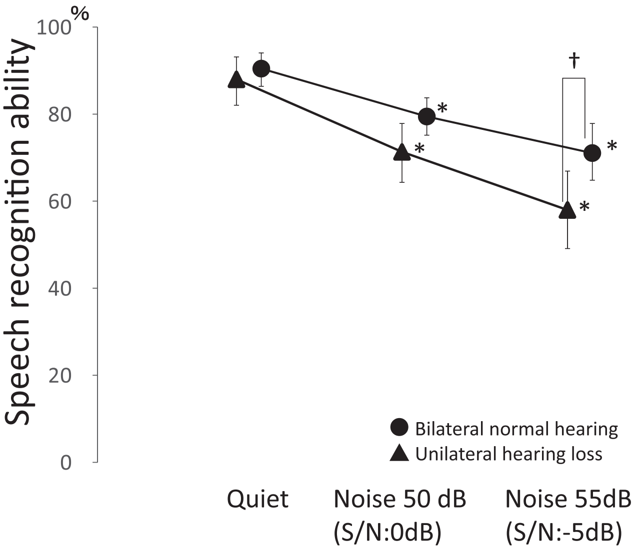

Fig. 2
Effects of noise on speech recognition ability in children with unilateral hearing loss and bilateral normal hearing. Triangles and circles represent children with unilateral hearing loss and with bilateral normal hearing, respectively. *$p < 0.05$ vs. quiet, †$p < 0.05$ between groups. Data presented as mean ± standard deviation.

In other unaided children with unilateral severe-to-profound hearing loss, the correct rates of speech recognition test were 88.0 ± 3.0% (n=10) in quiet, 64.0 ± 12.3% (n=10) and 58.4 ± 11.1% (n=9) in noisy environments of 50 and 55 dB WN, respectively. Thus, the correct rates of speech recognition test were significantly decreased in noisy environments of 0 and -5 dB SNR, compared with those in quiet environment in unaided unilateral hearing deficit children. When they were aided by a FM receiver into the normal hearing ear, the correct rates of speech recognition test were 89.2 ± 4.0% (n=10) in quiet, 84.8 ± 6.7% (n=10) and 78.7 ± 6.4% (n=9) in noisy environments of 50 and 55 dB WN, respectively. Thus, in children with unilateral hearing loss, the correct rates of speech recognition test when aided were maintained in noisy environments of 50 and 55 dB WN (0 and -5 dB SNR) and significantly increased, compared those when unaided in the noisy environments ($p < 0.01$) (Fig. 3).

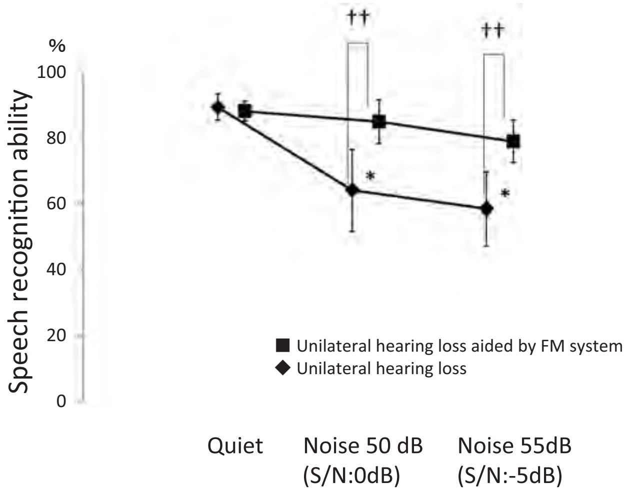

Fig. 3
Effects of FM system on speech recognition ability in noise in children with unilateral hearing loss. Diamonds and squares represent unaided and aided with Open-fit FM system into the normal hearing ear, respectively. *$p < 0.05$ vs. quiet ; ††$p < 0.01$ between unaided and aided with FM system. Data presented as mean ± standard deviation.

The averaged noise level in six elementary school classrooms was 68.4 dB SPL, while the averaged speech level of teachers' talk in the classrooms was 73.5 dB SPL. Both levels were obtained by the data logging system of open-fit Oticon's Epoq XW hearing aid on teacher's auricle without gain. Since the sound pressure levels of teacher's talk were attenuated with a decrease of 12.0 dB at a typical preferred seating location (see Methods), an estimated speech level of 61.5 dB SPL would be delivered to students with hearing loss, resulting in -6.9 dB SNR in Japanese elementary school classrooms (Table 1).

DISCUSSION

In the present study, speech recognition ability of Japanese children with unilateral severe-to-profound hearing loss was similar to that of age-matched children with bilateral normal hearing in quiet and slight noisy (50 dB WN) environments. However, in louder noise environment of 55 dB WN, speech recognition ability of children with unilateral hearing loss decreased, compared with that of children with bilateral normal hearing. Since unilateral hearing loss is a disruption of binaural processing of the auditory system including binaural summation, head shadow effect and localization (2), it was reported that children with unilateral hearing loss encounter difficulty understanding speech under noisy environments (13, 14). A recent report also indicated that children with unilateral severe-to-profound hearing loss required at least 2-9 dB better SNR than children with normal hearing for understanding speech in noisy environments (15).

Typical classrooms have been found to have an SNR of +6 dB in USA and an SNR of+11 dB in Canada, which were calculated with

Table 1 Noise level and signal to noise ratio in classrooms

	School A	School B	School C	School D	School E	School F	average
Noise level in classroom	69.5	67.5	73.1	70.8	63.0	66.7	68.4 dB SPL
Level of teacher's talk	74.5	72.1	75.6	74.6	69.3	74.4	73.5 dB SPL
Estimated level of teacher's signal at preferential seat	62.5	60.1	63.6	62.9	57.3	62.4	61.5 dB SPL
Estimated S/N at preferential seat	-7.0	-7.4	-9.5	-7.9	-5.7	-4.3	-6.9 dB

S/N : signal to noise ratio.

background noise level in quiet classrooms (2, 16). However, in the present study, the acoustic condition in Japanese elementary school classrooms was a -6.9 dB SNR, which was calculated from ambient noise in the active classroom measured by the data logging system in Oticon's Epoq XW hearing aid. Since even in normal hearing, younger children require a greater SNR than older children when listening in noise (17), it is suggested that hearing assistive devices are needed for Japanese elementary school children with unilateral hearing loss in noisy environments, particularly in a classroom.

In the present study, a FM receiver fitted into the normal hearing ear improved the speech recognition ability of children with unilateral hearing loss in noisy environment of 55 dB WN like the listening condition in Japanese elementary school classrooms. CROS and bone-anchored hearing aids (BAHA) (18, 19) may be used as another audiological management for children with unilateral hearing loss in noisy classrooms. They can make use of neurophysiological mechanisms of binaural hearing and improve the hearing ability of children with unilateral hearing loss in noisy environments (20). On the other hand, the FM system picks up relevant teacher's voice in a short distance and delivers it to the listener's ear through radio waves that do not interfere with surrounding ambient noises. The FM system can directly improve the SNR of auditory signals. Moreover, it has no side effect contrary to the BAHA implantation that needs an invasive procedure and occasionally causes post-operative complications such as skin irritation and failure of osseointegration (21). In fact, a previous study reported that the FM system improved the word recognition of children with unilateral hearing loss in the typical classroom acoustic condition of +6 dB SNR in USA, compared with CROS and conventional hearing aids (8). Taken together, the findings of the present study also suggest that the FM system is recommended as an audiological management for improvement of speech recognition in noisy elementary school classrooms for Japanese children with unilateral hearing loss. But, children with unilateral hearing loss may encounter difficulty in hearing classmate's talk during they are hearing teacher's talk using FM system, although inactive open-fit FM receiver on the normal hearing ear dose not interfere in listening classroom discussion.

CONCLUSION

The present study demonstrated that the FM system that consists of a microphone worn by the teacher and a receiver applied to the student's normal ear overcomes the listening difficulties of children with unilateral severe-to-profound hearing loss in nosy elementary school classrooms in Japan. In Tokushima prefecture of Japan, about 75% of children with unilateral hearing loss preferred to use the FM system in classrooms, probably because they felt some benefit for classroom instructions and discussions. The beneficial effects of the FM system need to be examined in children with varying degrees and types of unilateral hearing loss and in various noise conditions. Further research should also include a comparison between the FM system and BAHA as an audiological management for children with unilateral severe-to-profound hearing loss.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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