Research Article

Correlation between Aural/Oral Performance and Fit-to-Target Gain among Children with Moderate-to-Profound Hearing Loss Aged 5–10 Years

Yousef Reyhani[1], Farzaneh Fatahi[1*], Elham Tavanai[1], Hamid Jalilvand[2], Shohreh Jalaie[3]

[1.] *Department of Audiology, School of Rehabilitation, Tehran University of Medical Sciences, Tehran, Iran*
[2.] *Department of Audiology, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran, Iran*
[3.] *School of Rehabilitation, Tehran University of Medical Sciences, Tehran, Iran*

Use your device to scan and read the article online

Citation: Reyhani Y, Fatahi F, Tavanai E, Jalilvand H, Jalaie S. Correlation between Aural/Oral Performance and Fit-to-Target Gain among Children with Moderate-to-Profound Hearing Loss Aged 5–10 Years. Aud Vestib Res. 2023;32(4):302-13.

https://doi.org/10.18502/avr.v32i4.13594

Highlights

- REM increases the accuracy of prescribing HAs to children with HL
- The degree of HL affects the aural/oral performance of hearing impaired children
- Better fit to target leads to better PEACH score of children with HL

Article info:
Received: 10 Apr 2023
Revised: 22 May 2023
Accepted: 28 May 2023

[*] **Corresponding Author:**
Department of Audiology, School of Rehabilitation, Tehran University of Medical Sciences, Tehran, Iran.
jfatahi@tums.ac.ir

ABSTRACT

Background and Aim: Real-Ear Measurement (REM) enables proper fitting of the hearing aids to achieve the required level of amplification. This study aims to investigate the relationship between aural/oral performance and fit-to-target gain of hearing aids in children with moderate-to-profound hearing loss.

Methods: This cross-sectional study was conducted on 30 children with moderate-to-profound hearing loss aged 5–10 years. First, the parents' evaluation of aural/oral performance of children (PEACH) questioanire was completed. Then, REM was performed using digital speech at 50, 65, 80, and 90 dB SPL at 250–8000 Hz to obtain the fit to the desired sensation level, version 5 (DSL v5) target gain.

Results: A significant negative correlation was found between the total score of the PEACH (51.66) and the fit-to-target gain at high frequencies (r=–0.482, p=0.01). The maximum fit-to-target gain was 77.5 dB for 65 dB SPL at 6000 Hz. Most of the cases (75%) failed to come within ±5 dB of the target gain. There was a significant difference in the fit-to-target gain between low and high frequencies and between high frequencies with similar input levels.

Conclusion: A negative correlation between aural/oral performance of children with moderate-to-profound hearing loss and fit-to-target gain of their hearing aids may indicate that a low fit-to-target gain can improve their aural/oral performance. Regular use of REM is recommended in prescribing hearing aids to these children.

Keywords: Children; fit to target gain; hearing loss; aural/oral performance

Introduction

Hearing is essential for language, speech, and cognitive development [1]. Hearing loss is one of the most common disorders in the world [2]. Approximately 7.3% of people with hearing loss are children [3]. Hearing loss is the most common sensory deficit in infants and is caused by several reasons, such as genetic, environmental, and congenital factors [4]. Permanent hearing loss in childhood has significant negative impacts on children's psychosocial functioning and academic performance [5]. The hearing-impaired children can use hearing aids or cochlear implants to prevent delays in speech and language development and improve cognitive development in early childhood [6]. These devices are used to bring back the ability to hear soft sounds, increase intelligibility of conversational speech, and provide comfort for hearing loud sounds [7]. The prescription of hearing aids for children in the audiology clinics is often based on the first fit. The first fit is often based on target gain extracted from audiometric thresholds [8]. The hearing aids prescriptions based on target gain can lead to better speech perception in quiet or in noise or better subjective quality than the prescriptions that differ significantly from the target [9]. Various studies have shown that the first fit does not produce the desired results based on prescriptive formulas [10]. Hearing aids prescription applications overestimate the real ear gain, especially at high frequencies [11]. For children, there are two ways to verify hearing aid prescription: Real-Ear Measurement (REM) using probe microphone and simulated REM by age-matched Real-Ear-to-Coupler Difference (RECD) method [12]. Thus, during the verification procedure, the use of REM ensures that the in-ear performance of hearing aids meets the specified prescribed criteria [13]. Baumfield and Dillon reported that, as gain deviation from the prescribed gain formula increased from 0 to 6 dB, the reported benefit by users decreased [14]. Kirkwood found that only 35% of audiologists used REM instruments most or almost most of the time [15]. Evaluation of hearing aid prescription outcomes in children should cover different aspects including audibility, speech perception, subjective value, and speech production. Audibility can be determined by measuring amplified hearing thresholds or REM [16]. REM is crucial and compulsory for children [14]. It provides clinicians with a valid and reliable approach for verifying hearing aid output in the ear. REM is associated with improved function in noise, higher user satisfaction, user comfortability, audibility enhancement, and better understanding of delivered services [17-19].

Some surveys have investigated discrepancies in the target gain by REM between first-fit and programmed-fit settings [11, 20]. Sanders et al. fitted five mini receiver-in-canal digital hearing aids from five brands on eight patients with sloping high tone loss. The Real-Ear Aided Response (REAR) measurement at 55, 65 and 75 dB Sound Pressure Levels (SPL) was used to fit hearing aids based on national acoustic laboratories, nonlinear version 2 gain (NAL-NL2). The results demonstrated that the gain for 55 dB SPL was below NAL-NL2 target gain in 74% of the subjects. At 65 dB SPL, the fitted gain was below the target gain at least at a frequency from 250 to 4000 Hz in 55% of the subjects. For most fittings, the gain above 2000 Hz was below the NAL-NL2 gain and the gain at 75 dB SPL was above the target gain [21]. In another study on measuring the goodness of hearing aid fit [22], Munro et al. evaluated 100 bilateral fits (51 closed with custom earmolds). The hearing aids were fitted based on the manufacturer algorithm to the NAL-NL1 target gain using the Real-Ear Insertion Gain (REIG). They assessed the Goodness of Fit (GoF) where "0.0" indicated a very poor fit, and "1.0" showed an ideal fit to target at all frequencies. GoF was calculated based on three measures: a) close fit: difference between REIG and target gain at each frequency, b) similar shape: difference in the shape of REIG and target gain, and c) adequate gain: difference between target and total REIG. Before fitting based on REIG, 18%, 50%, and 61% of the open-fit and 20%, 63%, and 67% of the closed-fit were within 10 dB of target gain at 50, 65, and 80 dB SPL, respectively. After fitting, 85% of open-fit and 90% of close-fit were within 10 dB of target gain for all input levels. They reported an average GoF of 0.6–0.8 for the close-fit at 50, 65, and 80 dB SPL using the first-fit setting and 0.8–0.9 for the fitting programmed by REIG [20, 22]. Seewald et al. suggested that newborns and children probably depend on fitting hearing aid based on prescriptive approaches, because they are generally unreliable in behavioral tests and cannot give feedback to help audiologists fit the hearing aids. Therefore, it is vital to check the children's hearing aids to fit them to the targets and ensure that the maximum output does not surpass the prescribed levels [23].

Recent studies have demonstrated that subjective tests based on observational reports are valuable for assessing the children's communication and listening skills [23, 24]. One of these tests is the parents' evaluation of aural/oral performance of children (PEACH), which evaluates the effectiveness of amplification for infants and young children with hearing impairment using hearing aids by a systematic use of parents' observations [25]. Naghibirad et al. translated and validated the Persian version of this scale [26]. There is scant research on the effect of fit to target gain on children's aural/oral performance [27, 28], and there is little information about the effect of difference between real and target gains on children's speech development [29]. In addition, the children's speech development can be affected by several factors such as age and age at onset of wearing hearing aid. Therefore, there is a need to evaluate whether it is possible to use fit to target to predict the aural/oral performance of children. Thus, this study aims to evaluate the fit of the real-ear gain to the target gain based on the prescribed formula in hearing-impaired children aged 5–10 years wearing hearing aids by REM method, and to assess their aural/oral performance using the PEACH scale.

Methods

Participants

This is a cross-sectional study that was approved by the Ethics Committee of Tehran University of Medical Sciences (Code: IR.TUMS.FNM.REC.1401.108). Participants were 30 children with hearing impairment using hearing aids recruited from three child hearing assessment clinics (Alvand, Pezhvak, and Pezhvak 88) in Tehran, Iran using a convenience sampling method. Their parents signed an informed consent form. The inclusion criteria were: Age 5–10 years, bilateral symmetrical sensorineural hearing loss, auditory thresholds of 50–70 dB HL at 250–1000 Hz and 60–120 dB HL at 2000–8000 Hz, having a healthy middle ear and tympanic membrane (normal otoscopy and type An tympanogram), ability to keep the head steady during the measurement, and wearing hearing aids for at least 8 hours a day. Those who had narrow ear canals or were candidates for cochlear implantation and those whose parents were unwilling to participate in the study were excluded. Children`s demographic information (the cause of hearing loss, parents' family history of hearing loss, age at diagnosis of hearing loss, age at the onset of wearing hearing aids, and age at onset of participation in auditory training interventions) were obtained through interviews with their parents. An inclusive audiological test was carried out to certify that the participants were eligible, if they had not undergone an audiological test in the past 6 months. Air conduction thresholds were determined at octave and mid-octave intervals from 250 to 8000 Hz, and bone conduction thresholds were assessed at octave and mid-octave intervals from 250 to 4000 Hz using an Aurical audiometer (Madsen, USA), an HB7 headphone (TDH 39P), and a bone transducer (RadioEar B71). All children were using Bilateral Behind-the-Ear (BTE) hearing aids with similar features. The hearing aid prescription process included a hearing assessment, hearing aid fitting using the manufacturer first-fit algorithm, and ensuing follow-up appointments. The hearing aids had already been fitted by other audiologists and the researchers did not change their fitting. In cases with referral to the centers, the hearing aids were adjusted based on the feedback of the child and parents during the follow-up sessions.

Measures

Parents' evaluation of aural/oral performance of children scale

The Persian version of the PEACH scale with acceptable validity and reliability (Cronbach's alpha=0.91 and intraclass correlation coefficient=0.99) [26] was used to evaluate the performance of children using hearing aids. It assess device usage and loudness discomfort, listening and communication performance in quiet and in noise, telephone usage, and responses to environmental sounds. The items are rated on a five-point Likert scale as: 0 (no auditory response occurred), 1 (auditory response occurred 25% of the time), 2 (auditory response occurred 50% of the time), 3 (auditory response occurred 75% of the time), and 4 (auditory response occurred more than 75% of the time). The questionnaire has three sections. The first section has 2 items about the use of hearing aids. The second section has 6 items about listening and communicating in quiet places. The third section has 5 items about listening and communicating in noisy situations. The scores for the items related to the sections 2 and 3 are summed up to calculate the total performance score.

The necessary explanation was given to the parents. After obtaining their informed consent, they received the Persian version of PEACH and a supplemental guide on how to fill out it. To complete the PEACH scale, the parents were asked to observe the child for at least one week and record their observations in a booklet specific to hearing aid users. One week later, the scores were determined during a meeting with parents and an audiologist.

Otoscopy and tympanometry

Otoscopy and tympanometry were performed. All subjects had normal, healthy-appearing ear canals and tympanic membranes.

Real-ear measurement

The reference microphone and probe microphone were first calibrated. The child was asked to sit on a chair located approximately at the center of the audiometric test booth, at least 4 feet far from the wall and 12 inches from the center of the head. The probe microphone's loudspeaker placed at a 45-degree azimuth from the participant`s nose. The probe tube insertion depth was determined by placing it 5 mm beyond the medial tip of the earmold [30]. Then, a digital speech stimulus (ANSI-weighted) was provided for 14 seconds at 50, 65, and 80 dB SPL and the REAR was measured. In addition, real ear saturation response was measured using a pure tone stimulus at 90 dB SPL. The values related to the target gain based on the Desired Sensation Level (DSL) v5 were extracted from FONIX FP35 hearing aids the analyzer and fitting to target was obtained. We adopted a commonly accepted criterion according to which a fit to target of<5 dB is considered optimal for a prescription [30, 31].

Statistical analysis

Demographic characteristics and test data were described using descriptive statistics. Data distribution normality was checked using the Kolmogorov-Smirnov test. To determine the correlation between the aural/oral performance scores (in quiet, in noise, and total) and the fit-to-target gain at different frequencies at 50, 65, 80, and 90 dB SPL, the Pearson's correlation test was applied, if there was a normal distribution; otherwise, the Spearman`s test was used. Repeated measures ANOVA was used to compare the fit-to-target gain at 50, 65, 80, and 90 dB SPL at different frequencies, if the data distribution was normal; otherwise, Friedman test was used. Linear regression was used to predict the aural/oral performance based on age at onset of auditory training. p≤0.05 were statistically significant. All statistical analyses were carried out in SPSS v.17 software (SPSS Inc., Chicago, IL, USA).

Results

The demographic characteristics of the participants are shown in Table 1. All BTE hearing aids (n=60) of children had different models available on the market. All hearing aids were fitted using occluding soft earmolds. The fit-to-target value was measured for 60 ears at 50, 65, 80, and 90 dB SPL by an experienced audiologist. The mean value of the two ears was considered as the fit-to-target for each child. The maximum fit-to-target value was 77.5 dB for 65 dB SPL at 6000 Hz. The distribution of the fit-to-target data for 50 dB SPL at 2000, 4000, 6000, and 8000 Hz was normal, but it was not normal at 250, 500 and 1000 Hz (p<0.05). Regarding the fit-to-target data for 65 dB SPL at 250, 1000, 2000, 4000, 6000, and 8000 Hz, the data had a normal distribution, while it was not normal at 500 Hz (p=0,016). The fit-to-target data for 80 dB SPL was normal at 250, 1000, 2000, 4000, and 6000 Hz, but it was not normal at 500 and 8000 Hz (p<0.05). The fit-to-target data for 90 dB SPL was normal at all frequencies. As can be seen in Figure 1, the amount of REAG increased with the increase of hearing thresholds from low to high frequencies. Of 60 fittings, 75% could not reach the ±5 dB of the DSL v5 target gain at one or more frequencies from 250 to 8000 Hz. The results of the failure rate are presented in Table 2.

Repeated measures ANOVA or its nonparametric equivalent, the Friedman test, was used depending on the distribution of the fit to target values. Repeated measures ANOVA showed a significant difference in the fit-to-target gain between different frequencies ($F_{(2.94, 85.43)}$=50.03, p<0.001). In addition, the Friedman test also showed a significant difference in the fit-to-target gain between different frequencies (p<0.001). The results of pairwise comparisons are presented in Table 3.

The results showed no significant difference in the fit-to-target gain between input levels at 500 and 1000

Hz, while it was significantly different between all input levels at 4000 and 6000 Hz (p<0.05). The results are shown in Figure 1. The mean hearing threshold (dB HL) and ±1 SD for the 30 participants were demonstrated in Figure 2. Hearing thresholds at 250–8000 Hz were not normally distributed (p<0.05). The results of Spearman's test showed a significant correlation between the fit-to-target gain for 50 dB SPL at 4000 Hz (r=0.47, p=0.009) and 8000 Hz (r=0.51, p=0.003) and the hearing threshold for 65 dB SPL at 4000 Hz (r=0.52, p=0.003) and 8000 Hz (r=0.52, p=0.003) and the hearing threshold for 80 dB SPL at 4000 Hz (r=0.51, p=0.004) and 8000 Hz (r=0.55, p=0.001). For 90 dB SPL, there was no significant correlation between the fit-to-target gain and hearing threshold at any frequency. The data related to aural/oral performance in quiet had normal distribution, while the data related to the performance in noise (p<0.001 and the total score had abnormal distribution (p=0.007). The results for the PEACH scale are presented in Table 4. The results of the correlation test between the fit-to-target gain and aural/oral performance are shown in Table 5. According to the results, the fit-to-target gain had a negative correlation with aural/oral performance in quiet, aural/oral performance in noise, and total performance at high frequencies.

Table 1. Demographics characteristics of subjects (n=30)

Variables	Subjects
Age:	
Mean(SD)	6.86(1.75)
Gender (n):	
Female	14
Male	16
Causes of hearing loss (n):	
Genetic	9
Family marriage	8
Premature birth	10
Seizure	2
Jaundice	1
Family history of hearing loss (n):	24
Age at diagnosis of hearing loss (n):	
At birth	7
6 Months	1
1 year old	22
Age at receive hearing aid (n):	
1 year old	8
1.5 years old	22
Age at start of hearing training (n):	
1 year old	11
1.5 years old	7
2 years old	6
2.5 years old	5
3 years old	1
Hearing aids (n):	
Phonak	Audéo P50 312 (n=2)
	Bolero B70-SP (n=2)
	Naida B50-UP (n=1)
	Naida M50-SP (n=1)
Signia	Motion SP 5px (n=4)
	Motion 13P 5Nx (n=2)
Unitron	T Max 500 UP (n=4)
	Max 6 SP (n=2)
Oticon	Xceed 3 UP (n=2)
	Dynamo SP4 (n=2)
	Dynamo SP6 (n=2)
Rexton	Mosaic P 60 6C (n=3)
A&M	XTM P P8 (n=3)

The results of the correlation test indicated a significant negative correlation between age at diagnosis of hearing loss and aural/oral performance in quiet (r=–0.485, p=0.007), aural/oral performance in noise (r=–0.535, p=0.002), and total performance (r=–0.481, p=0.007). A significant negative correlation was found between age at onset of auditory training and aural/oral performance in quiet (r=–0.755, p<0.001), aural/oral performance in noise (r=–0.839, p<0.001), and total performance (r=–0.784, p<0.001). Linear regression analysis was conducted to determine the contribution of independent variables in predicting aural/oral performance. Age at onset of auditory training had a significant relationship with the aural/oral performance in quiet (R^2=0.52, p<0.001). Regression analysis was be performed on the other variables because normality and collinearity assumptions were met.

Discussion

In this study, we assessed the fit-to-target gain for hearing aid fitting based on the DSL v5 targets in children aged 5–10 years with moderate to profound sensorineural hearing loss. Hearing aids were selected from different models and were eligible if the hearing thresholds were in the fitting range for the specific hearing aid. We tested all hearing aids using a digital speech at three input levels (50, 65, and 80 dB SPL) using pure tones at 90 dB SPL, and the difference between REAG and targets was calculated to determine the fit-to-target gain at 250–8000 Hz. The REAG makes it easy to visualize the relationships between evaluation data, level of unaided speech, and amplification features [22].

value more than 5 dB. This may be due to severity of hearing loss, technical limitations of hearing aids, or earmold changes since the first fit [31, 32]. The failure rate was 64% [10] and 73% [32]. The discrepancy in results may be related to the difference in participants (children vs. adult) and criterion (±10 dB vs. ±5 dB). The patients had better hearing thresholds in the study by Aazh and Moore [10]. Quar et al. used a different frequency range (500–4000 Hz) [33].

The results of the present study showed a significant difference in the fit-to-target gain between low and high frequencies ($p<0.05$). It was observed more at high frequencies. This is consistent with previous studies [33, 34]. The reason for this finding is that, according to Hawkings and Cook [11], the software overestimates the real-ear gain at high frequencies and acoustic feedback prevents excessive gain above 3000 Hz [35], which may increase the fit to target at high frequencies. The maximum fit to target was 77.5 dB for 65 dB SPL at 6000 Hz. In line with our results, Folekeard et al. found that most fittings at 6000 Hz fell outside the ±5 dB of the target [34].

In our study, the fit to target was significantly different

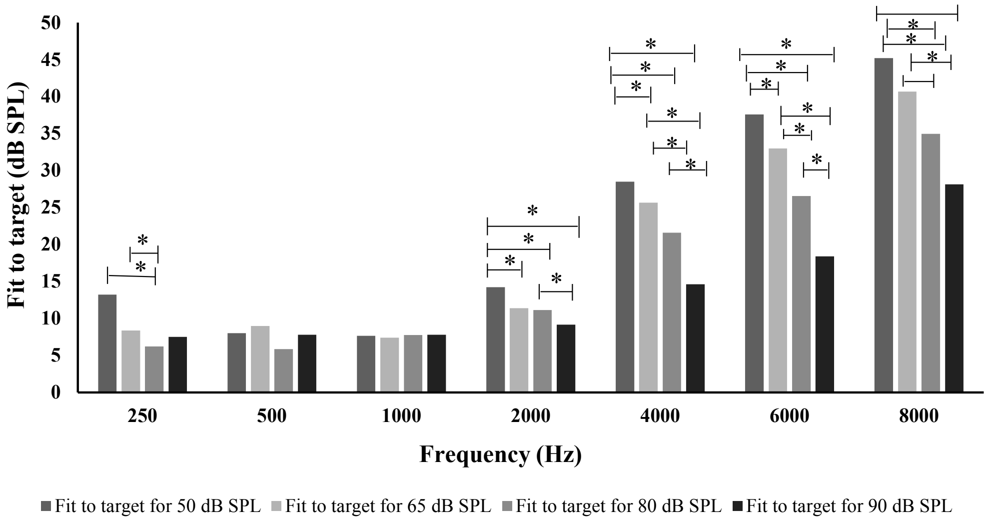

Figure 1. Real-ear measurement setup. The patient sat approximately at the center of the test booth at least 4 feet from the wall. Reprinted from operator's manual of FONIX® FP35 Touch hearing aid analyzer ver.8.11, chapter 5, page 118, with permission from Frye Electronics, Inc.

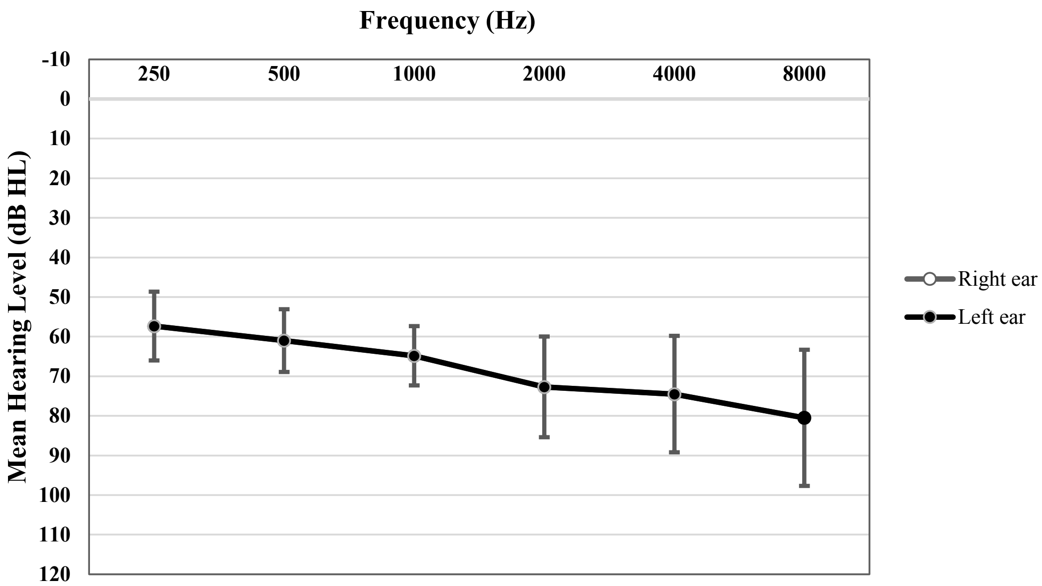

Figure 2. Audiogram reporting the mean±one SD for hearing thresholds (dB HL) in the left (●) and right (○) ear

Table 2. Total number of cases for each frequency (cases for which desired sensation levels version 5 recommended a target real ear aided gain), number of cases that failed at each audiometric frequency, and percentage of cases that failed to fit to target

Frequency (Hz)	Number of cases	Number of fails	Percentage of fails
250	30	18	60
500	30	18	60
1000	30	19	63.33
2000	30	24	80
4000	30	27	90
6000	30	28	93.33
8000	30	29	96.66

Table 3. Comparison of fit to target for 50, 65, 80, and 90 dB SPL at 250–8000 Hz (n=30)

	Fit to target for			
	50 dB SPL	65 dB SPL	80 dB SPL	90 dB SPL
Frequency (Hz)	p	p	p	p
250 and 500	0.411[b]	0.781[b]	0.496[b]	1.000[a]
250 and 1000	0.304[b]	1.000[a]	1.000[a]	1.000[a]
250 and 2000	1.000[a]	1.000[a]	0.084[a]	1.000[a]
250 and 4000	0.000[*a]	0.003[*a]	0.000[*a]	0.577[a]
250 and 6000	0.000[*a]	0.000[*a]	0.000[*a]	0.038[*a]
250 and 8000	0.000[*a]	0.000[*a]	0.000[*b]	0.000[*a]
500 and 1000	0.572[b]	0.607[b]	0.094[b]	1.000[a]
500 and 2000	0.002[*b]	0.063[b]	0.000[*b]	1.000[a]
500 and 4000	0.000[*b]	0.000[*b]	0.000[*b]	0.172[a]
500 and 6000	0.000[*b]	0.000[*b]	0.000[*b]	0.014[*a]
500 and 8000	0.000[*b]	0.000[*b]	0.000[*b]	0.000[*a]
1000 and 2000	0.000[*b]	1.000[a]	1.000[a]	1.000[a]
1000 and 4000	0.000[*b]	0.000[*a]	0.002[*a]	1.000[a]
1000 and 6000	0.000[*b]	0.000[*a]	0.002[*a]	0.089[a]
1000 and 8000	0.000[*b]	0.000[*a]	0.000[*b]	0.000[*a]
2000 and 4000	0.000[*a]	0.001[*a]	0.015[*a]	1.000[a]
2000 and 6000	0.000[*a]	0.000[*a]	0.013[*a]	0.013[*a]
2000 and 8000	0.000[*a]	0.000[*a]	0.000[*b]	0.000[a]
4000 and 6000	0.003[*a]	0.025[*a]	1.000[a]	1.000[a]
4000 and 8000	0.000[*a]	0.000[*a]	0.000[*b]	0.000[*a]
6000 and 8000	0.353[a]	0.644[a]	0.001[*b]	0.006[*a]

[a] Post hoc analysis with a Bonferroni adjustment used to compare pairwise, [b] Post hoc analysis with Wilcoxon signed-rank tests with a Bonferroni correction used to compare pairwise, [*]alpha=0.05.

In the present study, 75% of the children failed to reach ±5 dB of the DSL v5 target gain at one or more frequencies from 250 to 8000 Hz. This is consistent with the findings of several studies reported that the calculated output of the hearing aids in a many children fitted to a particular prescription target had a fit-to-target

Table 4. Results related to aural/oral performance of the cases (n=30).

Parents' evaluation of aural/oral performance of Children score	Mean±SD	Minimum	Maximum
Quiet	53.05±8.47	29.16	70.83
Noise	49.54±9.82	20.00	70.00
Total	51.66±8.64	25.00	70.45

Table 5. Correlation between fit to target for 50, 65, 80 and 90 dB SPL and scores of parents' evaluation of aural/oral performance of children (n=30).

Fit to target for		50 dB SPL		65 dB SPL		80 dB SPL		90 dB SPL	
Frequency (Hz)	**Scores of PEACH**	**Correlation coefficient (r)**	**p**	**Correlation coefficient (r)**	**p**	**Correlation coefficient (r)**	**p**	**Correlation coefficient (r)**	**p**
250	Quiet	0.00*	0.975	-0.15*	0.422	-0.15*	0.422	-0.30*	0.102
	Noise	0.02**	0.885	0.14**	0.444	0.14**	0.444	0.26**	0.154
	Total	0.00**	0.990	0.14**	0.436	0.14**	0.436	0.28**	0.130
500	Quiet	-0.18**	0.321	-0.03**	0.851	-0.03**	0.851	-0.08*	0.654
	Noise	-0.18**	0.331	-0.09**	0.609	-0.09**	0.609	-0.07**	0.685
	Total	-0.13**	0.472	0.01**	0.943	0.01**	0.943	-0.10**	0.596
1000	Quiet	0.01**	0.944	-0.14*	0.427	-0.14*	0.427	0.014*	0.432
	Noise	-0.00**	0.971	-0.15**	0.179	-0.15**	0.179	0.14**	0.460
	Total	0.02**	0.898	-0.17**	0.456	-0.17**	0.456	0.16**	0.379
2000	Quiet	-0.19*	0.313	-0.18*	0.328	-0.18*	0.328	-0.15*	0.428
	Noise	-0.24**	0.198	-0.28**	0.129	-0.28**	0.129	-0.10**	0.574
	Total	-0.22**	0.224	-0.25**	0.179	-0.25**	0.179	-0.15**	0.403
4000	Quiet	-0.49*	0.005*	-0.40*	0.026*	-0.40*	0.026*	-0.30*	0.097
	Noise	-0.47**	0.009*	-0.40**	0.025*	-0.40**	0.025*	-0.28**	0.133
	Total	-0.48**	0.006*	-0.40**	0.025*	-0.40**	0.025*	-0.34**	0.063
6000	Quiet	-0.41*	0.023*	-0.42*	0.019*	-0.42*	0.019*	-0.43*	0.016*
	Noise	-0.33**	0.071	-0.36**	0.048*	-0.36**	0.048*	-0.44**	0.014*
	Total	-0.38**	0.037*	-0.39**	0.029*	-0.39**	0.029*	-0.48**	0.007*
8000	Quiet	-0.39*	0.030	-0.41*	0.022*	-0.41**	0.022*	-0.27*	0.140
	Noise	-0.28**	0.133	-0.31**	0.086	-0.31**	0.086	-0.19**	0.295
	Total	-0.35**	0.055	-0.37**	0.039*	-0.37**	0.039*	-0.29**	0.120

PEACH; Parents' Evaluation of Aural/Oral Performance of Children

* Pearson's correlation test was used to assess correlation between fit to target and aural/ oral performance, **Spearman's correlation test was used for variables with abnormal distribution, * alpha=0.05

at 4000 and 6000 Hz for all input levels. Consistently, Quar et al. showed that the input level had a significant effect on the fit to target [33]. In addition, Folekeard et al. found that the fit to target may depend on the input level [34]. We found a significant correlation between the fit-to-target gain for 50, 65, and 80 dB SPL inputs (4000, 8000 Hz) and the hearing threshold at these frequencies. Consistent with our results, Folekeard et al. reported that with the increase of high-frequency hearing loss severity, the fit-to-target gain decreases. Overall, their results indicated that the fitting accuracy decreases with the increase of hearing impairment [34].

In the present study, the scores of the PEACH scale in quiet, in noise, and its total score were 53.05±8.47, 49.54±9.82, and 51.66±8.64, respectively. Ching and Hill also reported norm values for moderate to profound hearing loss [27]. The aural/oral performance in quiet had a significant correlation with the fit-to-target gain at 50, 65 dB SPL (4000, 6000, and 8000 Hz), 80 dB SPL (4000, 6000 Hz), and 90 dB SPL input levels (8000 Hz). The aural/oral performance in noise had a significant correlation with the fit-to-target gain at 50, 65, 80 dB SPL (4000 Hz), and 90 dB SPL (250 Hz) input levels. The total score of the aural/oral performance had a significant correlation with the fit-to-target gain at 50, 65 dB SPL (4000, 6000 Hz), and 80 dB SPL (4000 Hz) input levels. The correlation coefficient values were moderate and negative indicating that with the decrease in the fit to target, aural/oral performance improved moderately. In agreement with our results, McCreey et al. reported that children using hearing aids with gain lower than target gain at all input levels had significantly lower scores in perceiving amplified speech compared to the children whose hearing aids were within ±5 dB of target at some levels during verification, and this change was most noticeable for children who were under fitted at high frequencies [29]. The PEACH scores are affected by the degree of hearing loss; the higher the hearing loss, the lower the PEACH score [36]. Ching et al. found that the NAL response was the best for 66% of subjects, based on the PEACH score [27]. In the study by Golding et al, the PEACH score had a significant correlation with objective measures of audibility based on cortical auditory-evoked responses in infants [37]. Also found similar results in adults [38].

Based on the result of this study, age at diagnosis of hearing loss and age at onset of auditory training had a significant negative correlation with aural/oral performance. Linear regression model showed that age at onset of auditory training could significantly predict the aural/oral performance in quiet. Consistent with our results, Moller found a graded association between language outcomes and age at diagnosis [6]. Therefore, early detection and intervention can help many children with hearing loss to perceive near-normal speech and language as plotted by growth charts using standard language points [39]. According to Pungello et al., socioeconomic conditions and parenting style may have an effect on early childhood aural/oral skills [40]. Thus, the parenting behaviors (e.g., maternal responsive and intrusive behaviors), maternal education level, family stress, and parent-child relationship can also affect the children's language development [41].

In addition to the above-mentioned factors, other factors can affect the fit-to-target gain. According to Aazh and Moore, 100% of fitting for the hearing aids with seven bands was within ±10 dB of the target gain. It seems that the possibility of fitting to target gain is greater for hearing aids with more bands. In addition, the average slope of the audiogram from 2000 to 4000 Hz was significantly higher for those that did not fit to target [10]. The next affecting factor is the multicentricity of the study. McCreery et al. indicated a significant difference in the Root Mean Square (RMS) error between different studies; the study that performed clinical fittings at a single center had fewer RMS errors in fitting to targets than a study that performed fitting at multiple centers [31]. Another factor is the method of obtaining the REAR [42]. The audiologist's experience can also affect the degree of fit-to-target gain [43]. the earmold quality can also be an effective factor. Accurate fit to targets of a valid prescription seems to be even more important for those with more severe hearing loss, compared to those with mild hearing loss, not only because the amount of audible signal received with amplification was limited by their confined dynamic range [44], but also because they were less skilled in deriving speech information from a signal even when amplification made it audible [45]. In our study, different models of hearing aids were used.

Limitations

This study was conducted on children with moderate-to-profound hearing loss. Since aural/oral performance is affected by hearing impairment and the criterion for the degree of hearing loss is very broad, it is recommended to choose a narrower criterion for a more detailed investigation (e.g., on children with moderate-to-severe or severe-to-profound hearing loss) in future studies. Considering that the specifications of hearing aids should be the same for similar hearing loss, it is recommended that users with the same hearing aids be selected as samples in future studies.

Conclusion

The REM method has been proposed as the gold standard for hearing aid fitting and can improve the fit-to-target gain. However, very few audiologists use this method routinely in daily practice. On the other hand, improper fitting can have negative impact on the hearing-impaired children's speech and language development. The results demonstrated a negative correlation between the fit-to-target gain and aural/oral performance in children with moderate-to-profound hearing loss. This highlights the importance of REM in the prescription of hearing aids to these children.

Ethical Considerations

Compliance with ethical guidelines

The current study took into account all ethical considerations recommended by Tehran Medical University Sciences and approved the study with its Code of Ethics IR.TUMS.FNM.REC.1401.108. Furthermore, participation in this study was based on obtaining informed consent from all parents.

Funding

The present study has been supported by Tehran University of Medical Sciences with grant no. 1401-4-103-64555.

Authors' contributions

YR: Study design, acquisition of data, interpretation of the results, statistical analysis, and drafting the manuscript; FF: Study design, interpretation of the results, and drafting the manuscript; ET: Study design, interpretation of the results, and drafting the manuscript; HJ: Study design, monitoring the study, interpretation of the results, and drafting the manuscript; SJ: Statistical analysis.

Conflict of interest

No potential conflict of interest relevant to this article was reported.

Acknowledgments

We also sincerely thank all the participants for their cooperation in this study.

References

[1] Robinshaw HM. Early intervention for hearing impairment: Differences in the timing of communicative and linguistic development. Br J Audiol. 1995;29(6):315-34. [DOI:10.3109/03005369509076750]

[2] World Health Organization. WHO Global Estimate on Prevalence of Hearing Loss. Geneva: World Health Organization; 2012. Available from: http://www.who.int/pbd/deafness/estimates.

[3] World Health Organization. Deafness and Hearing Loss. Geneva: World Health Organization; 2018. Available from: http://www.who.int/mediacentre/factsheets/fs300/en/

[4] Chari DA, Chan DK. Diagnosis and Treatment of Congenital Sensorineural Hearing Loss. Curr Otorhinolaryngol Rep. 2017;5(4):251-8. [DOI:10.1007/s40136-017-0163-3]

[5] Moeller MP. Early Intervention and Language Development in Children Who Are Deaf and Hard of Hearing. Pediatrics. 2000;106(3):e43. [DOI:10.1542/peds.106.3.e43]

[6] Finitzo T, Albright K, O' Neal J. The Newborn with Hearing Loss: Detection in the Nursery. Pediatrics. 1998;102(06):1452-60. [DOI:10.1542/peds.102.6.1452]

[7] Kennedy CR, McCann DC, Campbell MJ, Law CM, Mullee M, Petrou S, et al. Language Ability after Early Detection of Permanent Childhood Hearing Impairment. N Engl J Med. 2006;354(20):2131-41. [DOI:10.1056/NEJMoa054915]

[8] Scollie S, Seewald R, Cornelisse L, Moodie S, Bagatto M, Laurnagaray D, et al. The Desired Sensation Level multistage input/output algorithm. Trends Amplif. 2005;9(4):159-97. [DOI:10.1177/108471380500900403]

[9] Byrne D, Dillon H, Ching T, Katsch R, Keidser G. NAL-NL1 procedure for fitting nonlinear hearing aids: characteristics and comparisons with other procedures. J Am Acad Audiol. 2001;12(1):37-51. [DOI:10.1055/s-0041-1741117]

[10] Aazh H, Moore BCJ. The Value of Routine Real Ear Measurement of the Gain of Digital Hearing Aids. J Am Acad Audiol. 2007;18(08):653-64. [DOI:10.3766/jaaa.18.8.3]

[11] Hawkins DB, Cook JA. Hearing aid software predictive gain values How accurate are they? Hear J. 2003;56(7):26,28,32,34. [DOI:10.1097/01.HJ.0000292552.60032.8b]

[12] American Academy of Audiology. Clinical Practice Guidelines: Pediatric Amplification. Reston: American Academy of Audiology; 2013.

[13] Keidser G, Dillon H, Flax M, Ching T, Brewer S. The NAL-NL2 Prescription Procedure. Audiol Res. 2011;1(1):e24. [DOI:10.4081/audiores.2011.e24]

[14] Baumfield A, Dillon H. Factors affecting the use and perceived benefit of ITE and BTE hearing aids. Br J Audiol. 2001;35(4):247-58. [DOI:10.1080/00305364.2001.11745243]

[15] Kirkwood DH. Survey finds most dispensers bullish, but not on over-the-counter devices. Hear J. 2004;57(3):19-20,24-26,28,30. [DOI:10.1097/01.HJ.0000292370.19215.93]

[16] Arlinger SD. How to assess outcome of hearing aid fitting in children. Scandinavian Audiology. 2001;30(2):68-72. [DOI:10.1080/010503901750166709]

[17] Kochkin S. MarkeTrak VIII: Reducing patient visits through verification and validation. Hear Rev. 2011;18(6):10-2.

[18] Leavitt R, Flexer C. The importance of audibility in successful amplification of hearing loss. Hear Rev. 2012;19(13):20-3.

[19] Kirkwood DH. Survey: Dispensers fitted more hearing aids in 2005 at higher prices. Hear J. 2006;59(4):40. [DOI:10.1097/01.HJ.0000286695.28587.f5]

[20] Hostler ME. A'Goodness of Fit calculator'. BSA News. 2004;43.

[21] Sanders J, Stoody T, Weber J, Mueller HG. Manufacturers' NAL-NL2 fittings fail real-ear verification. Hear Rev. 2015;21(3):24-32.

[22] Munro KJ, Puri R, Bird J, Smith M. Using probe-microphone measurements to improve the match to target gain and frequency response slope, as a function of earmould style, frequency, and input level. Int J Audiol. 2016;55(4):215-23. [DOI:10.3109/14992027.2015.1104736]

[23] Seewald RC, Ross M, Spiro MK. Selecting Amplification Characteristics for Young Hearing-Impaired Children. Ear Hear. 1985;6(1):48-53.

[24] Allum JHJ, Greisiger R, Straubhaar S, Carpenter MG. Auditory Perception and Speech Identification in Children with Cochlear Implants Tested with the EARS Protocol. Br J Audiol. 2000;34(5):293-303. [DOI:10.3109/03005364000000141]

[25] Young NM, Grohne KM. Comparison of Pediatric Clarion Recipients with and Without the Electrode Positioner. Otol Neurotol. 2001;22(2):195-9.

[26] Naghibirad F, Fatahi J, Hajiabolhassan F, Faghihzadeh E, Emamdjomeh H. Cultural adaptation and determination of validity and reliability of the Persian version of the parents' evaluation of aural/oral performance of children questionnaire. Aud Vestib Res. 2016;25(2):111-8.

[27] Ching TY, Hill M. The Parents' Evaluation of Aural/Oral Performance of Children (PEACH) scale: normative data. J Am Acad Audiol. 2007;18(3):220-35. [DOI:10.3766/jaaa.18.3.4]

[28] Ching TY, Hill M, Dillon H. Effect of variations in hearing-aid frequency response on real-life functional performance of children with severe or profound hearing loss. Int J Audiol. 2008;47(8):461-75. [DOI:10.1080/14992020802116128]

[29] McCreery RW, Brennan M, Walker EA, Spratford M. Perceptual Implications of Level- and Frequency-Specific Deviations from Hearing Aid Prescription in Children. J Am Acad Audiol. 2017;28(9):861-75. [DOI:10.3766/jaaa.17014]

[30] ASHA Ad Hoc Committee on Hearing Aid Selection and Fitting. Guidelines for Hearing Aid Fitting for Adults. Am J Audiol. 1998;7(1):5-13. [DOI:10.1044/1059-0889.0701.05]

[31] McCreery RW, Bentler RA, Roush PA. Characteristics of hearing aid fittings in infants and young children. Ear Hear. 2013;34(6):701-10. [DOI:10.1097/AUD.0b013e31828f1033]

[32] Ching TY, Quar TK, Johnson EE, Newall P, Sharma M. Comparing NAL-NL1 and DSL v5 in Hearing Aids Fit to Children with Severe or Profound Hearing Loss: Goodness of Fit-to-Targets, Impacts on Predicted Loudness and Speech Intelligibility. J Am Acad Audiol. 2015;26(3):260-74. [DOI:10.3766/jaaa.26.3.6]

[33] Quar TK, Umat C, Chew YY. The Effects of Manufacturer's Prefit and Real-Ear Fitting on the Predicted Speech Perception of Children with Severe to Profound Hearing Loss. J Am Acad Audiol. 2019;30(5):346-56. [DOI:10.3766/jaaa.16150]

[34] Folkeard P, Bagatto M, Scollie S. Evaluation of Hearing Aid Manufacturers' Software-Derived Fittings to DSL v5.0 Pediatric Targets. J Am Acad Audiol. 2020;31(5):354-62. [DOI:10.3766/jaaa.19057]

[35] Libby ER. Measures to Verify Achievement of Desired Real-Ear Gain in Adults. Semin Hear. 1991;12(1):42-52. [DOI:10.1055/s-0028-1090015]

[36] Bagatto M, Moodie S, Brown C, Malandrino A, Richert F, Clench D, et al. Prescribing and Verifying Hearing Aids Applying the American Academy of Audiology Pediatric Amplification Guideline: Protocols and Outcomes from the Ontario Infant Hearing Program. J Am Acad Audiol. 2016;27(3):188-203. [DOI:10.3766/jaaa.15051]

[37] Golding M, Pearce W, Seymour J, Cooper A, Ching T, Dillon H. The relationship between obligatory cortical auditory evoked potentials (CAEPs) and functional measures in young infants. J Am Acad Audiol. 2007;18(2):117-25. [DOI:10.3766/jaaa.18.2.4]

[38] Abrams HB, Chisolm TH, McManus M, McArdle R. Initial-fit approach versus verified prescription: comparing self-perceived hearing aid benefit. J Am Acad Audiol. 2012;23(10):768-78. [DOI:10.3766/jaaa.23.10.3]

[39] Yoshinaga-Itano C, Baca RL, Sedey AL. Describing the trajectory of language development in the presence of severe-

to-profound hearing loss: a closer look at children with cochlear implants versus hearing aids. Otol Neurotol. 2010;31(8):1268-74. [DOI:10.1097/MAO.0b013e3181f1ce07]

[40] Pungello EP, Iruka IU, Dotterer AM, Mills-Koonce R, Reznick JS. The effects of socioeconomic status, race, and parenting on language development in early childhood. Dev Psychol. 2009;45(2):544-57. [DOI:10.1037/a0013917]

[41] Quar TK, Ching TY, Mukari SZ, Newall P. Parents' evaluation of aural/oral performance of children (PEACH) scale in the Malay language: data for normal-hearing children. Int J Audiol. 2012;51(4):326-33. [DOI:10.3109/14992027.2011.637079]

[42] Hawkins D. Reliability of three types of probe tube microphone measurements. Hearing Instruments. 1991;42:12-6.

[43] Swan IR, Gatehouse S. The value of routine in-the-ear measurement of hearing aid gain. Br J Audiol. 1995;29(5):271-7. [DOI:10.3109/03005369509076742]

[44] Byrne D. Key issues in hearing aid selection and evaluation. J Am Acad Audiol. 1992;3(2):67-80.

[45] Ching TY, Dillon H, Katsch R, Byrne D. Maximizing effective audibility in hearing aid fitting. Ear Hear. 2001;22(3):212-24. [DOI:10.1097/00003446-200106000-00005]