A battery of tests for fitting hearing aid to single sided deafness client – a case report

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ABSTRACT
For a patient with single-sided deafness (SSD), it was observed that a hearing aid programmed to unmasked thresholds resulted in no intolerance to amplified speech and eliminated a sensation of vibration. Further, the binaural advantage was assessed using localization and speech in noise tests and the programmed settings were found to be beneficial in the aided condition compared to the unaided condition. Further, the hearing aid trial was performed using a paired comparison method by occluding the better ear with an otoblock and speech noise was delivered using insert earphone at 65 dB SPL. The aided benefit in each hearing aid was best when occluding the better ear with an otoblock. But the findings indeed require further systematic design on a cohort of SSD before coming into concluding remark.

Background
A single-sided deafness (SSD) or unilateral hearing loss is defined as a profound hearing loss with poor word recognition scores in one ear and normal hearing in the opposite ear [1]. The majority of these patients complain of marked intolerance for amplified sound [2]. The age of onset of SSD can be either congenital or acquired at a later stage and its incidence is greatest between 30 and 60 years. Prevalence of SSD is in every 1000 SNHL adults, three individuals are affected from SSD [3]. The common problems encountered by these patients are difficulty in understanding speech in noise, difficulty in localization and reduced loudness due to monaural hearing or loss of binaural summation [4]. Most of SSD patients during communication tend to turn their head frequently to put the better ear towards the signal of interest [5]. They subjectively report that when a noise is present on the side of the better ear it is more difficult to understand speech which leads to communication breakdown [6]. To rehabilitate individuals with SSD there are devices available such as cochlear implant and bone anchored hearing aid but due to high cost they cannot afford it. In addition some subject reluctant for surgery which is required to implant the above mentioned device. The presented case is neither affords the cost nor agreed for surgery. Thus, to mitigate their problem a hearing aid is one among several rehabilitative options available [7]. Benefit from a hearing aid improves binaural advantage in them [8]. However, a clinician should understand the cross over or interaural attenuation phenomenon before fitting a hearing aid to SSD. It is important to know how much of the signal delivered to poorer ear crosses over to normal ear to ensure the patient does not experience a sensation of vibration and/or intolerance. This is because the user had 92 dB HL and 0 speech recognition threshold (SRT) on the affected side. In this case the hearing aid cannot aid any useful information to the affected inner ear, especially given that the other ear is good. Thus, the test hearing aid in the present study was programmed by utilizing both the unmasked and the masked thresholds of the poorer ear. To objectively evaluate, skull attenuation (Ac affected ear – BC unaffected ear) should be determined by using real ear measurements (REM). This is done to see if the hearing aid gain is appropriately fit REM and it is utilized because of its objectivity and it accounts for characteristics of the individual’s ear; and measures sound pressure levels developed within an ear canal using a probe tube microphone. Further, there is a need to document validation of patient’s benefit from hearing aid. Validation measure includes...
subjective outcome such as speech in noise, localization and loudness growth function should be considered as these measures assess the individual’s listening benefit. In the present study, these tests were performed in unaided and aided conditions in which a hearing aid gain was programmed using unmasked and masked thresholds of the poorer ear to assess the hearing aid benefit. The purpose was to determine whether to program a hearing aid using unmasked or masked thresholds. The research question put forth from this study is during validation procedure of hearing aid performance is using masking noise or an otoblock in the better ear would be best to avoid participation and to determine accurate aided performance in the poorer ear. Thus, both objective and subjective measures were utilized to evaluate the setup to fit the hearing aid to the unilateral hearing loss patient and also to overcome the skull attenuation from the output amplified speech to reach the unaffected ear without causing discomfort.

A case report

A 15 year old male patient arrived with a complaint of reduced hearing sensitivity in the right ear since childhood. He also reported marked speech understanding difficulty especially when noise was present on the side of the left ear or when a talker is on the side of the right ear. After case history and ontological examination, a detailed audio logical evaluation was completed. Conventional pure-tone audiometry revealed a profound hearing loss in the right ear (92.5 dB HL) and normal hearing sensitivity in the left ear (15 dB HL) (Figure 1). Speech audiometry was completed in each ear. The SRT was 10 dB and 100% speech identification score (SIS) on the left ear. Whereas on right ear no measurable SRT and SIS upon masking noise delivered to left ear to avoid its participation. Tympanometric evaluation revealed ‘A’ type on both ears, indicative of normal middle ear status. Left ear ipsilateral and right ear contralateral reflexes were present from 500 Hz to 4 kHz (in octaves). Whereas, right ear ipsilateral and left ear contralateral reflexes were present at each frequency from 500 Hz to 4 kHz (in octaves). Otoacoustic emissions (OAE) testing documented the presence of transient OAE in left ear and absence of transient and distortion product OAEs in right ear. Auditory brain stem response was administered to assess space occupying lesion. A click stimulus of 1500 sweeps were presented through insert receiver earphones at 90 dB HL at two repetition rates. It was found that that peak latency of V was less than 0.8 ms between two repetition rates of 11.1 and 90.1 s in the left ear. However, in the right ear there was no identifiable wave V peak.

Real ear measurement

The PhonakNaida Q 50 UP digital behind the ear hearing aid was connected to HiPro which in turn was connected to a computer with NOAH software. The patient’s unmasked hearing thresholds were entered in the audiogram module. Through the hearing aid software, the hearing aid was detected. The prescriptive formula NAL–NL1 was selected to prescribe gain appropriate to the participant’s hearing loss. The patient was seated 12 inch from a

Figure 1. Audiogram of right and left ears.
loudspeaker at a 45° azimuth. The probe tube of the Fonix 7000 system was inserted into the ear canal. The probe tube was marked 5 mm past the end of the custom ear mold. The probe tip was inserted into the ear canal until the marking of probe tube was at the tragal notch. The probe tube was calibrated. The real ear unaided response (REUG) was measured by presenting DigiSpeech signal at 65 dB SPL. The output SPL at the level of ear canal was measured at octave frequencies from 0.25 kHz to 8 kHz. Then hearing aid with custom earmould was placed into the ear canal without changing the position of the probe tube. The real ear aided response (REAG) was measured for the DigiSpeech signal at 65 dB SPL. It was ensured that REIG was matched to the prescriptive target with a differences of 2–3 dB across frequencies (Figure 2). Further, the patient’s masked hearing thresholds were entered in the audiogram module of NOAH software. The procedures explained earlier were performed to program the hearing aid and to verify its gain at patient’s ear canal.

It was observed that the REAG at each frequency for masked thresholds was greater than for unmasked threshold. The REAG obtained for the right ear for a hearing aid programmed using masked thresholds suggests that there would be a high chance of greater SPL reaching the better ear than REAG obtained from a hearing aid programmed using unmasked thresholds (interaural attenuation – REAG).

### Loudness growth in half octave bands

Loudness growth in half octave bands (LGOB) was assessed for 0.25, 0.5, 1, 2, and 4 kHz frequencies from 10 normal hearing subjects (baseline) and from the patient. (Figure 3). LGOB is a method that has been developed to assess and quantify loudness perception. This method accurately assesses loudness growth over signal intensities at each frequency. In this test, each participant was asked to rate the loudness at each frequency by assigning numerical values to the delivered intensities. The ratings were as follows: Too Loud-6; Very Loud-5; Loud-4; Ok-3; Soft-2 and Very Soft-1.

From Figure 3 it was observed that in the aided condition where hearing aid was programmed to masked thresholds the patient report of very loud for a signal intensity of 70 dB at each frequency. In addition, the patient reported a feeling of vibration. However, in the aided condition where the hearing aid was programmed to unmasked thresholds, the patient reported no vibration across the wide range of intensities (0–100 dB HL). Further, a similar loudness was noted to that of normal hearing individuals at each frequency. Thus, validation of aided performance was conducted on the patient where the hearing aid was programmed to unmasked thresholds and the digital noise reduction (DNR) circuit was activated. In this setting, localization and squelch effect were assessed to determine the binaural advantage.

### Localization

The LING sounds were delivered through Cubase 6 software and routed through a Lynx aurora signal router to the assigned loud speakers. A total of four loud speakers (Genelac 8020B) were used with the at 0°, 90°, 180° and 270° azimuth. The calibration of the stimuli was performed using Brueil and Kjaer (model no. 2270) sound level meter with a half inch free
field microphone. The loud speakers were placed 2 m away from the reference point. Each of the target LING stimuli was presented twice through the loud speakers in a random order. The participants were made to sit in the center (reference point) and were asked to locate the target stimuli either by pointing or stating the number of the loud speaker from which the target stimulus was heard. The experiment was conducted in both the unaided and aided conditions. Table 1 represents localization performance scores from for LING sound presented at the four azimuths in both the unaided and aided conditions.

It was observed that for each LING sound delivered at 0° and 270° the scores were same between unaided and aided conditions. Aided performance for 90° and 180° was clinically better than unaided condition.

Squelch effect

The listener’s ability of speech perception in noise was determined in both the unaided and aided conditions. The noise used was speech shaped noise and target speech stimuli were phonetically balanced words in Kannada [9]. In this method, three conditions were carried out in which the intensity of both speech and noise were presented at 45 dB SPL (i.e. 0 dB SNR). In each condition, the patient was instructed to repeat the words heard. The number of correctly identified words was noted down to assess the listener’s speech

Table 1. Localization scores in unaided and aided conditions.

| Condition | Azimuth /a/ /i/ /u/ /m/ /s/ /sh/ |
|-----------|-------------------------------|
| Unaided   |                               |
| 0° (Front)| 2/2 2/2 2/2 2/2 2/2 2/2 2/2 2/2 |
| 90° (Poorer side)| 1/2 0/2 0/2 0/2 0/2 0/2 0/2 0/2 |
| 180° (Back)| 1/2 1/2 1/2 1/2 1/2 1/2 0/2 0/2 |
| 270° (Better side)| 2/2 2/2 2/2 2/2 2/2 2/2 2/2 2/2 |
| Aided     |                               |
| 0° (Front)| 2/2 2/2 2/2 2/2 2/2 2/2 2/2 2/2 |
| 90° (Poorer side)| 2/2 2/2 2/2 2/2 2/2 1/2 1/2 1/2 |
| 180° (Back)| 2/2 2/2 2/2 1/2 1/2 1/2 1/2 1/2 |
| 270° (Better side)| 2/2 2/2 2/2 2/2 2/2 2/2 2/2 2/2 |

Figure 3. Loudness growth in half octave band in normal hearing subjects and client’s aided performance in which hearing aid was programmed to unmasked and masked thresholds.
perception ability. In first condition, both speech and noise were presented through a loudspeaker at 0° azimuth from a distance of 1 m. Results revealed 36% (9/25) and 44% (11/25) word recognition scores obtained in unaided and aided conditions, respectively. In the second condition, noise was presented through a loudspeaker that was positioned at 90° azimuth from a distance of 1 m on the poorer ear side and speech was presented through a loudspeaker that was positioned at 90° azimuth from a distance of 1 m on better ear side. The results revealed 84% (21/25) and 36% (9/25) word recognition scores were obtained in the unaided and aided conditions, respectively. In condition three, noise was presented from a distance of 1 m on the better ear side and speech was presented through a loudspeaker that was positioned on poorer ear side at 90° azimuth from a distance of 1 m. Result revealed that 28% (7/25) and 52% (13/25) recognition scores were obtained in the unaided and aided conditions, respectively.

**Hearing aid trial**

Before we conducted the hearing aid trial, the interaural attenuation was measured using an otoblock in the better ear. A otoblock is done with ear mold impression of better ear plus acoustic ear muffs (headphones in appearance). The probe microphone was inserted in the better ear. The SPL generated across frequencies from 250 Hz to 8 kHz were measured for the dig speech signal intensity of 65 dB SPL. In addition, without changing the position of the probe tube, the better ear was occluded with anotoblock and again a similar measurement was performed. It was observed that with the otoblock there was a significant attenuation (58 dB SPL) across frequencies than without.

We took two hearing aids for the purpose of the trial to choose the best hearing aid using the paired comparison method. The hearing aid settings that are selected using paired comparisons reflects patient’s relative judgment for the settings available for comparison. In addition comparison may result in a recommendation of the best hearing aid. The hearing aid gain was set to the patient’s unmasked threshold. This is because the patient reported similar loudness to that of normal hearing individuals at each frequency. Further, they reported no sense of vibration from the hearing aid which was programmed to the patient’s unmasked threshold.

Aided performances for standardized phrases [10] and words [9] in each hearing aid were obtained at 65 dB SPL delivered from a loudspeaker positioned at 0° azimuth from a distance of 1 meter, in which the better ear was masked with speech noise at 65 dB SPL through an insert receiver. Similarly, the entire procedure was performed by occluding the better ear with anotoblock. From Table 2, for each hearing aid, the aided performances for phrases and words were absent when the better ear was masked with speech noise. The masking noise of 65 dB SPL presented through insert earphone in better ear might have maximum ally interfered to perceive speech delivered at 65 dB SPL through loudspeaker positioned at 0° azimuth. However, for the condition where the better ear was blocked with anotoblock the aided performance for phrases was 60% and 80% and for words was 48% and 60% from Bernafone Xtreme 121 and Phonak Naida Q 50 UP, respectively.

**Discussion**

The REM reported that transcranial contra-later routing of signal gain/REIG was greater in the condition when the hearing aid was set according to masked thresholds than unmasked thresholds. To substantiate the objective measurement of REM and LGOB tests were administered. It was observed that loudness growth in the aided condition in which the hearing aid was programmed to masked thresholds, the patient reported very loud for the signal intensity of 70 dB at each frequency. Further, the patient experienced a sensation of vibration during normal conversations. When the hearing aid gain was set to unmasked thresholds the LGOB was closer to normal hearing individuals (Figure 2). In further evaluation to assess the binaural advantage, the hearing aid programmed to unmasked thresholds was considered. Localization was found to have clinically improved (Table 1). This could be due to benefit from the hearing aid. In binaural squelch test, when the signal was presented to the poorer ear and noise to the better ear (third condition) the performance from unaided condition was poorer than the aided condition. This is because in the unaided condition, a negative signal to noise ratio (SNR) at the better ear side caused a reduction in speech perception. In the unaided condition, the speech signal is on the side of poor ear and is attenuated by approximately 6.4 dB.

| Type of block | Hearing aid | Speech noise |
|---------------|-------------|--------------|
| Otoblock (ear mold with earphone) | Speech noise |

**Table 2. Hearing aid trial using paired comparison method.**

| Hearing aid | Otoblock (ear mold with earphone) | Speech noise |
|-------------|----------------------------------|--------------|
| Xtreme 121  | SIS score – 3/5                   | Phrases – 0/5 |
| Naida Q 50 UP| SIS score – 12/25                 | SIS score – 0/25 |
|            | SIS score – 15/25                 | Phrases – 0/5 |
|            | SIS score – 0/25                  | Phrases – 0/5 |

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to the good ear, while the noise is un attenuated to the good ear. In this condition, the SNR at the good ear is $-6\, \text{dB}$. Whereas for the aided condition, the hearing aid on the side of the poor ear deliver the amplified signal to the better ear either through air conduction or bone conduction there by eliminate the head shadow effect. Yet another reason could be selective segregation of neural train of noise and attend only to speech. In the second condition, the signal was presented from the better ear and noise to the poorer ear. The performance for the unaided condition was relatively better than the aided condition. This is because the better ear is directly receiving speech at $65\, \text{dB SPL}$ and the noise at $65\, \text{dB SPL}$ from the poor ear side. Noise from the side of the poor ear is reduced to the good ear by approximately $6.4\, \text{dB}$ due to head shadow effect. This reduces the noise level to $57.6\, \text{dB}$ at the side of good ear. Thus, this is a $+6\, \text{dB}$ positive SNR at better ear might have caused to result the best speech perception. Whereas, in aided condition the speech perception is poor. This is because noise is amplified and routed contralaterally to the better ear. The reduction of noise to the better ear has eliminated. Noise amplified at the poor ear mixed at high level with the unamplified speech entering the better ear effectively. In first condition, the aided performance was better than unaided condition. The SNR at the better ear was $0\, \text{dB SNR}$ and both speech and noise were at inaudible at poor ear. The effective process of selective segregation of neural train of noise and attend only to speech in better ear strains the auditory system to retrieve the information presented. Whereas, in the aided condition, there would be a reduction of noise due to DNR. Hearing aid fitted on poor ear amplifies the speech signal and then transcranially crosses over to the better cochlea. To summarize, validation procedures support the verification measure in which aided performance of localization and binaural squelch test were found to be better than the unaided condition.

For the hearing aid trial, apaired comparison method was utilized to select the best hearing aid. The better ear was occluded with using either the otoblock or speech noise to avoid participation and to obtain the accurate aided performance from poor ear. It was found that when better ear was occluded by the otoblock aided performance on phrases and words were better when masking the better ear with speech noise. Aided performance was best when better ear was otoblocked is could be due to the amplified output in the poorer ear is sufficient to reach the better cochlea through transcranially or above skull attenuation. Conversely, no aided responses were observed, when the better ear was masked by $65\, \text{dB}$ SPL noise. This is because the amplified speech signal routed transcranially to better cochlea was efficiently masked by noise presented to the better ear through insert earphone. It is something like a line busy effect in better ear by noise obstructs to retrieve the transcranially routed information from poorer ear. To conclude, the normal ear can detect speech in a negative SNR of approximately $-3\, \text{dB}$. Using an ‘otoblock’ will allow a speech signal from the contra lateral ear to reach the ‘good’ inner ear with a positive SNR ratio, and the signal will be detected. Using masking noise will risk making the SNR greater than $-3\, \text{dB}$ in the better ear, and thus impede speech recognition. Based on the scores on both hearing aids, the Phonak Naida Q 50 UP was prescribed to the client.

**Conclusions**

Programming the hearing aid using unmasked threshold of poor ear is reasonably best in fitting aid such that amplified speech overcomes the skull attenuation and also avoid an experience of vibration. In addition, instead of masking the better ear with noise, an otoblock is preferred to obtain accurate hearing aid benefit fitted in poorer ear. Otoblock method will allow a speech signal from the contra lateral ear to reach the unaffected ear with a positive SNR. Further, a validation of the hearing aid fitting should be assessed using localization and speech in noise test such that aided benefit experienced by the user can be determined. The finding of this case study indeed requires systematic design on a cohort of SSD to solve the following research questions (a) whether the unmasked thresholds of the poorer ear be used to program a hearing aid and further (b) is the better ear should be occluded with an otoblock to obtain accurate aided performance of the poorer ear.

**Disclosure statement**

No potential conflict of interest was reported by the author.

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