Research Article

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Efficacy of an Assistive Device for Museum Access to Persons with Hearing Impairment

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Abstract

Museum is a place of learning. Visit to the museum will be fruitful through effective interaction with the curator. Acoustic barriers in the museum prevent the curator's speech being intelligible to persons with hearing impairment. An assistive device was developed at AIISH to overcome the acoustic barriers for museum visitors with hearing impairment. The field trials of the device were conducted at the Regional Museum of Natural History, Mysuru. The study reported in this paper quantifies and critically evaluates the efficacy of the device in overcoming the acoustic barriers and making curator's speech audible and intelligible to the visitor. The efficacy measures employed were measurement of acoustic variables and feedback of the user through questionnaire. The results showed that, the device has been effective in overcoming the acoustic barriers for all visitors with hearing impairment, irrespective of their degree of hearing loss and the type of the hearing aid. The device has followed a universal design and hence is useful to all visitors to the museum.

Background

Museum is a place of infotainment that unveils a diversity of ideas to the visitors. A study conducted by Bowen, Greene, and Kisida (2014) on 3,811 students who visited the Crystal Bridges Museum of American Art, found that the critical thinking skills of the visitors were getting improved after the visit. Another study conducted on 10,912 students (Greene, Kisida, and Bowen, 2014) showed improvements in their critical thinking, historical empathy and tolerance, as a result of the museum visit. An article published in the New York Times, November 2013 (Kisida, Greene, & Bowen, 2013) suggests that, considering the benefits, regular visits to museums and galleries should be included as a part of the curriculum in schools. Thus, benefits accrued to a learner through a visit to the museum are well documented in the past research. Prime objective of any museum is to engage the community and also to educate them. Colleen (2009) shortlisted ten possible benefits of a museum visit, the most important one being the informal learning experience. Museum visits in groups can also lead to fruitful social relationship by becoming an active part of the community.

Proper interaction with the curators enhances the process of learning in a museum for any visitor. Room acoustics of the museum halls plays a crucial role to make this interaction fruitful. Smaldino, Crandell, Kreisman, John, and Kriesnan (2008) quoting Crandell, Smaldino, and Flexer (2005) has short listed three acoustic factors that affect speech recognition in a room. They are :- i. Speech signal-to-noise ratio (SNR), ii. The extent to which the time domain information of the speech signal is preserved and iii. The interaction between i & ii. If the background noise in a room is high, it has the potential to reduce speech recognition by masking the highly redundant acoustic cues (Nabelek & Nabelek, 1994). The sources of background noise in the museum include:- (i) external noise - the noise generated from outside the building such as traffic noise, streaking of vendors etc., (ii) internal noise- the noise generated within the building such as footsteps of visitors moving in the corridors, visitors talking to each other in neighbouring rooms and corridors etc. and (iii) hall noise - the noise generated within the hall where the visitor is. It includes noise due to visitors talking to each other, noise generated by shuffling of foot wares on the plain floor, fan noise etc. Thus, high background noise in museums leads to reduction in intelligibility of the curator's speech. Relationship between intensity of the speech signal and intensity of the background noise (SNR) at the listener's ear is the crucial factor affecting speech intelligibility (Crandell & Smaldino, 2000). Higher background noise in the museum hall will bring down the SNR to unfavorable levels. Reverberation refers to prolongation of sound inside a room due to reflection from surfaces such as walls, ceiling, floor and windows. Reverberation also degrades speech recognition through the masking of direct and early reflected energy by reverberant speech energy (Crandell & Smaldino, 2000). The reverberant speech energy reaches the listener after direct sound and overlaps with the direct signal resulting in smearing or masking of speech (Anderson, 2004). In most of the museums, noise and reverberation combine in a synergistic manner to adversely affect speech recognition. Curator-to-listener distance is another variable which add to the effects of reverberation, as reverberation dominates over direct sound with increase in distance from the curator (Crum, 1974).

Carvalho, Goncalves, and Garcia (2013) conducted a study on the acoustics of modern and old museums and arrived at the values of few acoustic variables. Measured values reported in their study are:- (i) Reverberation Time (RT) - 0.8 sec at 500 Hz, 1.4 sec at 1 kHz (ii) Rapid speech Transmission Index (RASTI) - 0.45 at 500 Hz, 0.65 at 1 kHz, (iii) Background noise level $\leq$45 dB. After measuring these variables in two museums, an old art museum and a modern museum, they observed that the values were away from the optimum values in both cases. Thus the acoustics in these museums was found to be not conducive for listening even for visitors with normal hearing. Technical Committee on Architectural Acoustics of the Acoustical Society of America (2000) has proposed a minimum SNR of +15dB, a distance of within 1-2 meters from the speaker, a Reverberation Time within 0.4 seconds and a Noise Reduction (NR) of 35 dB for a child with some kind of hearing impairment to have at least 90% speech intelligibility in classrooms. Listening environment in a museum is similar to that of a classroom. The values of the variables reported for modern and old museums were far away from these minimum requirements. These acoustic barriers prevent the visitors with hearing impairment from the accrued benefits of the museum visit. Gudrun (2006) analyzed the acoustical conditions at three museums in Denmark in terms of intelligibility, listening effort, noise distraction and speech privacy. The study came to a conclusion that the acoustics play a significant role in making the museum visit a comfortable one.

Limitations of hearing aids worn by person with hearing impairment in overcoming these acoustic barriers have been documented in many studies. Jerome and Patricia (2000) states that in poor acoustic conditions, hearing aids increase the listening difficulties rather than improving them. Anderson and Goldstein (2004) tested whether there is improvement in speech perception for eight 9-12 year aged children when they used assistive technology in addition to their hearing aids. The acoustic conditions were:- Reverberation Time of 1.1 second and SNR of 10dB, both far below the optimal values. They found that speech identification scores of 68.8 to 93.3 % obtained with hearing aid in these acoustic conditions improved to 86.7 to 100 % with the adoption of assistive technology. The hearing aid amplifies both the curator's speech and the noise and hence will not bring any significant change in the speech signal-to-noise ratio (SNR) and thus won't be able to maintain the optimal SNR of +15dB. When the museum is crowded, the visitor with hearing impairment will be away from the curator by more than the optimal distance of 2 meters. The effects of longer Reverberation Time will not be addressed by the hearing aid as the hearing aid can't differentiate the curator's sound and the reverberated sound.

One solution to overcome the acoustic barriers is to improve the acoustics. However, this requires expensive acoustic treatments. Moreover, there will be many practical limitations in providing such modifications in the existing structure. Another solution is to provide an assistive device for the visitor with hearing impairment, which will help to overcome the acoustic barriers.

The objective of the present study was to quantify and critically evaluate the efficacy of an assistive device developed by AIISH, Mysuru, when used by persons with hearing impairment during their visit to a museum. For this purpose, the Regional Museum of Natural History, Mysuru, was chosen where the said device had earlier underwent extensive field trials. The device was evaluated on four aspects:- a) its capability in overcoming the acoustic barriers at the museum b) functionality c) reliability and d) its adaptability to universal design.

Materials and Methods

Participants

The present study was conducted at Regional Museum of Natural History, Mysuru on 50 visitors with hearing impairment who were using either body worn or Behind The Ear (BTE) hearing aids. The age group distribution of the participants is shown in Figure 1.

Material

An assistive device, shown in figure 2, was developed at All India Institute of Speech and Hearing (AIISH), Mysuru which can be electromagnetically coupled with the hearing aid of the museum visitors with hearing impairment. The device underwent extensive field trials at the Regional Museum of Natural History, Mysuru. The neckloop attached

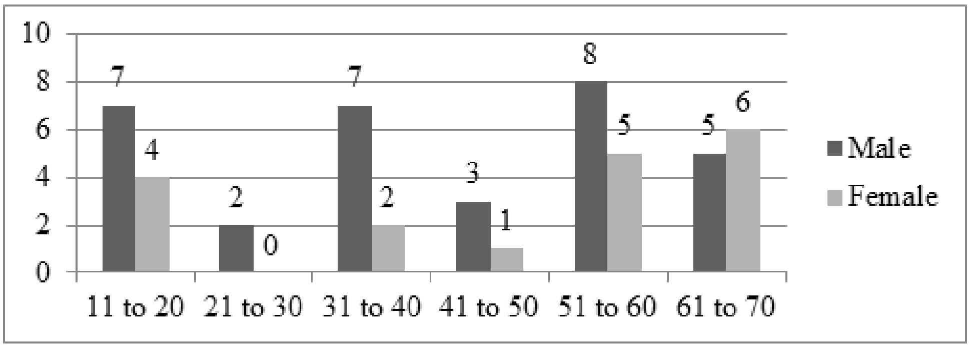


Figure 1: Age group distribution of participants of field trials.

Figure 2: Assistive device in operation.

to the device has to be worn on the neck of the user and the hearing aid has to be put in telecoil mode of operation. If the user doesn't have a hearing aid with telecoil option, he can still use the assistive device with headphone. Normal visitors can also use the device through the headphone. After connecting the neck loop / head phone, the user can enter the code number of the exhibit and press the '#' key on the key pad to start the pre-recorded commentary about the exhibit. The play status and the time of play will be shown on the LCD (Figure 2). The user can stop the commentary any time by pressing the '#' button.

Procedure

Smaldino et al. (2008) reviewed the different approaches those have been used in the past to document the effects of intervention to improve acoustics in the listening and learning, in a classroom set up. Observing on task behavior and measuring speech recognition scores were the approaches used in the previous studies. Both these methods have the inherent drawbacks such as the practical difficulties involved in conducting the test and the complexity of the test protocols. Hence, Smaldino et al. (2008) opined that subjective report questionnaires are the best media to obtain specific information on the efficacy of the intervention technology to overcome the acoustic barriers to communication. Thus, the efficacy measures used in the present study include:- i) Measurement of acoustic variables and ii) Subjective report questionnaire.

Measurement of acoustic variables: Acoustic variables were measured in the locations where the field trials of the assistive device were done. The variables measured include reverberation time, equivalent sound pressure level (LAeq) of noise and signal to noise ratio (SNR). All acoustic measurements were made with the precision sound Level Meter (B & K 2250) fitted with B & K 4189 free field measuring microphone or B & K 4192 pressure microphone. B & K 2734 power amplifier with built in white noise generator and B & K 4292 omnidirectional sound source were used for generating noise for RT measurements as illustrated in Figure 3. B & K B7228 building acoustic software was used for measurement of Reverberation Time.

Three representative locations were selected in the Regional Museum of Natural History, Mysuru for measurements, one at the entrance hall, one at the auditorium and one at the exhibit of a 'cave'. RT values were measured at three positions in each location at 500 Hz,1 kHz & 2 kHz and the average RT values were calculated. Measurement of the background noise was done at one position in

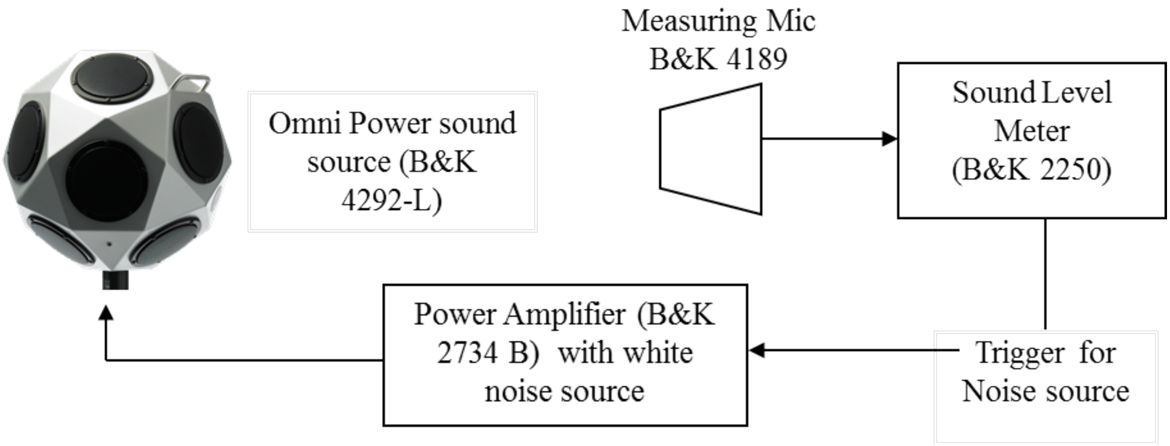


Figure 3: Assistive device in operation.

each location for octave band frequencies from 31 Hz to 8 kHz, each measurement for a duration of 10 minutes and the equivalent sound pressure level (LAeq) was noted using the precision Sound Level Meter.

The assistive device was issued to visitors with hearing impairment at the entry point of the museum. They were instructed to wear the neckloop and switch their hearing aids to telecoil mode of operation. The exhibits in the museum were coded. When the visitor reaches near the exhibit, the visitor will have to enter the respective code through the numerical keypad of the device and press the '#' button to hear a description about the exhibit through their hearing aids. If the visitor doesn't wear a hearing aid or doesn't have the telecoil option in their hearing aids, the visitor can still use the device by opting the headphone instead of neckloop.

Figure 4 shows the setup used for measurement of speech signal-to-noise ratio (SNR). The SNR at the input of the hearing aid was measured by placing the SLM microphone close to the location of the microphone of the hearing aid (Figure 4a). For Behind The Ear (BTE) hearing aids, the sound measuring microphone was kept at the ear level and for body worn hearing aid, the measurement was done at the pocket level. As illustrated in Figure 4a, B & K 4189 free field microphone coupled to B & K 2250 SLM were used for the measurement. The commentary of the exhibit was played through the headphone connected to the assistive device, during measurement of input SNR. The output SNR was measured by coupling the hearing aid output to the HA2 coupler (Figure 4b). The pressure microphone (B & K 4192) was kept inside the HA2 coupler and then coupled to the SLM (B & K 2250).

The output of the hearing aid was measured with the assistive device electromagnetically coupled to the hearing aid. At the time of measurement, the commentary about one of the exhibits was played through the assistive device.

Subjective report questionnaire

Feedback questionnaires in English / Hindi / Kannada (Appendix I, II & III respectively) were issued to the museum visitors to whom the assistive device was issued. The questionnaire was developed initially in English language and the questions were framed after considering the following :-

1. essential factors for proper functioning of the device.
2. major factors which decide the intelligibility of sound through the available output modes in the device.
3. factors required for proper use of the device.
4. appropriate suggestions from the experienced curators and museum visitors with hearing impairment.

Based on the above, the users were asked five questions. All the questions were provided with options and the user had to just tick the appropriate option. The first question was on connectivity between handset of the assistive device and the hearing aid device. The second was regarding the time taken by the assistive device to respond to the code entered by the user. The third one was on the intelligibility of speech through headphones. The fourth one was to judge the intelligibility of the description heard through the hearing aid when the hearing aid is coupled to the device. The last question was to find out whether the device was getting adequate backup from the battery.

These questions were given to five experienced curators and five museum visitors with hearing impairment to investigate whether the questions were correctly comprehended or not. They were asked to rate/categorize the questions into 'clear and meaningful', 'not clear' and 'unable to understand'. The questions rated as 'not clear' and 'unable to understand' were modified based on their suggestions.

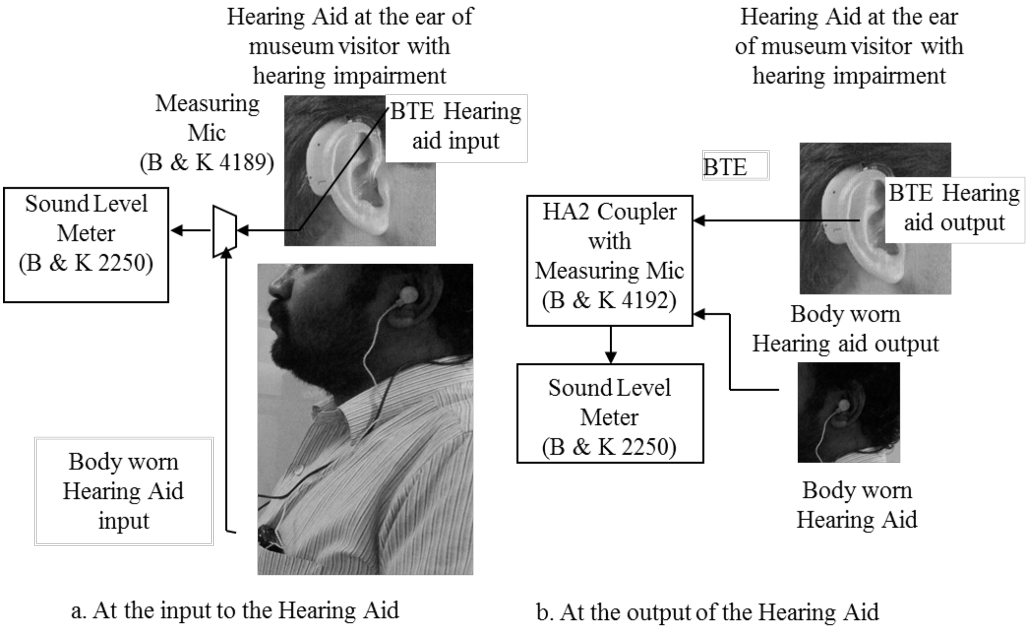


Figure 4: Setup used for measurement of speech signal-to-noise ratio (SNR).

Later the questionnaire was translated into Kannada & Hindi. Reverse translation of the questionnaire in English was carried out by two native speakers of Kannada and Hindi respectively and necessary corrections were incorporated. Later, the questionnaire developed in Kannada was given to five native speakers of Kannada for validation following the same procedure. The entire procedure was repeated for the developed questionnaire in Hindi and was validated by five native Hindi speakers

Analyses

The following analyses were carried out:- a) Analyses of the measured values of acoustic variables with and without the assistive device and b) Statistical analyses using SPSS software. Chi square test was carried out to find out the significance of association between the probable factors contributing to the efficacy of the device.

Results

Measurement of acoustic variables

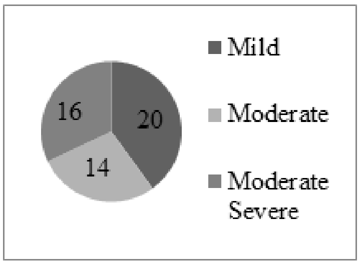
Table 1 shows that the measured values of acoustic variables such as background noise level, Reverberation Time (RT) and signal-to-noise ratio (SNR) at the three locations in the Regional Museum of Natural History, Mysuru and they were far from the optimal values reported by Carvalho et al. (2013).

Questionnaire

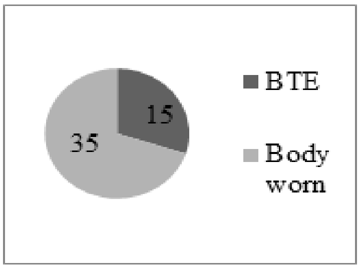
Distribution of participants according to their degree of hearing loss and the type of hearing aid worn are shown in Figure 5 a & b respectively. Figure 6 shows the feedback regarding connectivity of device with hearing aid of the visitors. Figure 7 shows the response of the device in executing the request for commentary by the user. Figure 8 shows the response of the user on the intelligibility of the speech heard through head phones and Figure 9 shows the intelligibility of the commentary heard

Table 1: Measured values of acoustic variables at RMNH, Mysuru

Acoustic variable	Location-1	Location-2	Location-3	Optimal values (Carvalho et al., 2013)
Background noise level (dB LAeq)	77.53	80.40	79.87	< 45
Reverberation Time (RT) in seconds (500, 1K, 2K)	1.98	2.68	1.77	< 0.80
Signal-to-Noise Ratio (SNR) (in dBA)	-7.5	-10	-8	> 0



(a) Degree of hearing loss of the participants



(b) Type of hearing aid worn by the participants

Figure 5: Characteristics of the participants

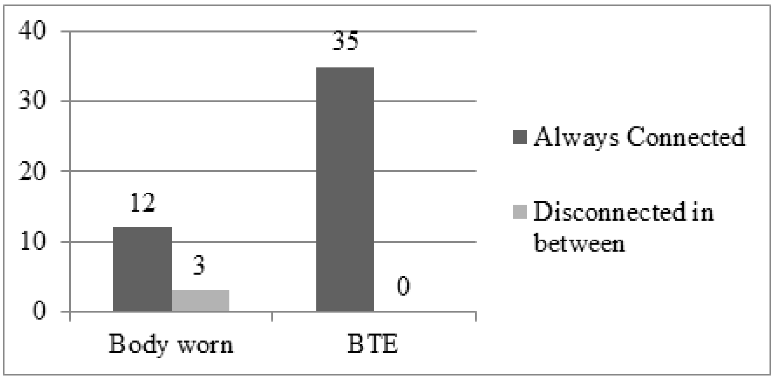


Figure 6: Response to connectivity of the device with hearing aid of the visitors.

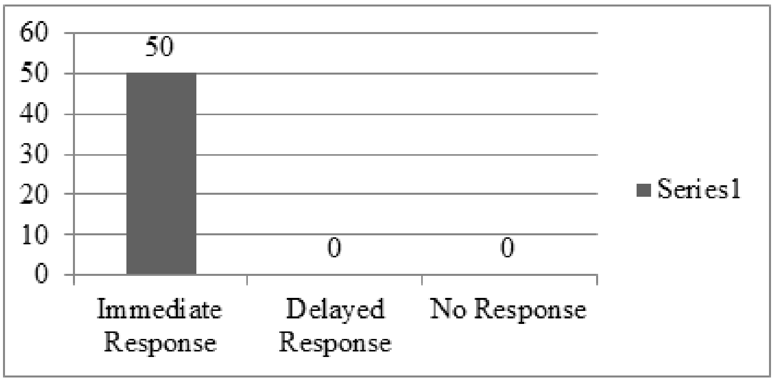


Figure 7: Response of the device towards a commentary request from the visitor.

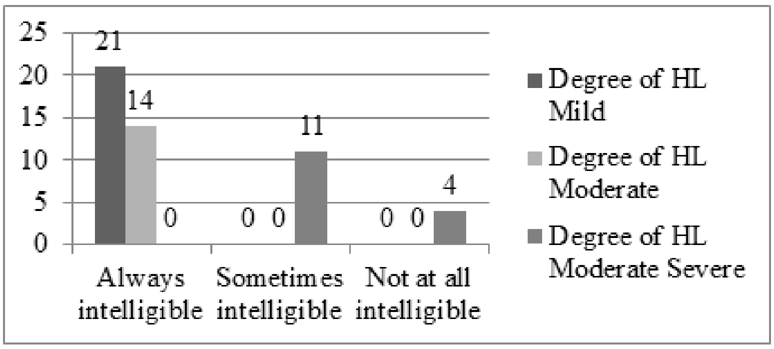


Figure 8: Feedback towards intelligibility of output sound through head phone across degree of hearing loss.

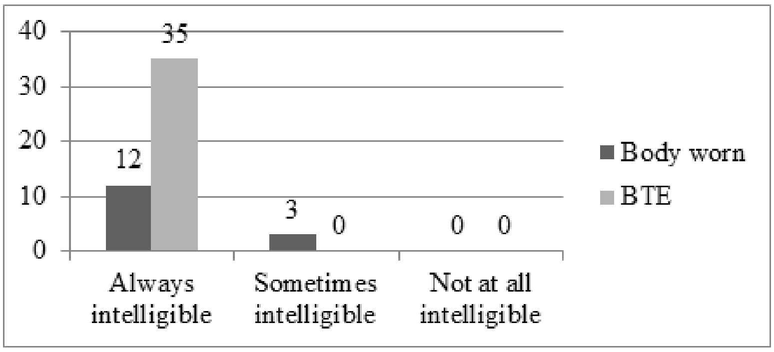


Figure 9: Feedback towards intelligibility of output sound through neck loop coupling across different hearing aids.

through the hearing aid, when coupled through the neckloop.

Discussion

Capability of the assistive device in overcoming the acoustic barriers at the museum

The enhancement in SNR when the assistive device is coupled to the hearing aid is evident from Table 2. The SNR values in both cases i.e., when the assistive device is coupled with Body worn hearing aids and when coupled with BTE hearing aids, were well above the minimum SNR limits reported by ASHA (2005) and ASA (2000). Noise levels at the output of both the hearing aids showed that they are well within the maximum optimum levels of background noise. The increase in SNR and the reduction in noise can be attributed to the fact that, the assistive device electro-magnetically coupled only the direct sound of the curator through the neckloop. Hence the reverberated sound was not carried through the electromagnetic coupling between the assistive device and the hearing aid. Thus the results indicate that the assistive device has removed the acoustic barriers for the visitors with hearing impairment.

Functionality

Functionality of the device was evaluated through the fourth question in the questionnaire. This question was framed to judge whether the speech with the assistive device coupled with the hearing aid was always intelligible, sometimes intelligible or not at all intelligible. Figure 9 reports the responses. All the users of BTE hearing aids commented that the speech was always intelligible, whereas in body worn hearing aid users, 3 out of 15 felt that the speech was intelligible only sometimes. The intelligibility of the sound from the BTE hearing aid depends on the fidelity of the neckloop. As the neckloop was properly designed with good frequency response, good intelligibility might have been achieved. Chi square test was done to find out whether there was any significant association between the type of hearing aid and the intelligibility. Results established ($\chi^2 = 7.447$, $p<0.01$) a significant association between the type of HA and intelligibility.

In the pocket type hearing aids, the telecoil which couples the electromagnetic signal from the neckloop of the assistive device, lies at the pocket level. When the visitor is moving, the neckloop may get shifted from its position, which might have resulted in “sometimes intelligible” opinion of three users. Chi square test ($\chi^2 = 6.782$, $p<0.05$ showed

Table 2: shows the measured values of the acoustic variables at the output of the hearing aid after coupling through the neckloop of the assistive device

Variable	Location-1	Location-2	Location-3
SNR (in dBA) with assistive device coupled to Body worn hearing aids	+24	+22	+19
SNR (in dBA) with assistive device coupled to BTE hearing aids	+32	+29	+27
Noise at the output of Body worn Hearing Aid (in dBA)	27	25	29
Noise at the output of BTE Hearing Aid (in dBA)	14	17	19

that there was no significant association between the degree of hearing loss and intelligibility. Thus, the results established that the functional objective of the device, to make the curator's speech audible and intelligible always, is accomplished.

Reliability

Reliability of the device was evaluated from the response of the user for 2 questions. The first question was regarding the connectivity of the hearing aid with the assistive device. Figure 6 shows that the user of Behind The Ear hearing aids reported that their aids were always connected with the assistive device. The probable reason could be the perfect electro magnetic coupling of the neckloop with the device. 20% of the body worn users experienced some disconnection in between, which may be due to the slipping of neckloop sometimes. Chi Square test ($\chi^2(2)= 7.447$, $p<0.05$) indicated a significant relationship between the type of hearing aid and connectivity. This indicated that the shifting of neckloop creates problem only for users of body worn hearing aids and not for BTE users.

The second question was regarding the response of the device towards a commentary request from the user. As shown in Figure 7, all users opined that there was immediate response from the assistive device. Thus, the reliability of the device in performing its functions has been validated. The reason for immediate response is due to the fact that, the system is controlled by a fast acting microcontroller.

Adaptability to universal design

A provision was made in the assistive device to route its output through headphones, so that the device can be used for visitors with normal hearing as well as for visitors who have hearing problems but not using hearing aids. The participants were requested to remove their hearing aids and listen to the commentary through headphones. As shown in figure 9, for visitors with mild to moderate hearing loss, the commentary was always intelligible through headphones. For visitors with moderately severe to profound loss, it was not intelligible always. Chi Square test ($\chi^2 = 50.00$, $p<0.001$) showed a significant relationship between the intelligibility through headphones and the degree of hearing loss. Thus, the device can be used for visitors with normal hearing as well as for visitors with moderately severe hearing loss even if they are not using their hearing aids. This proved that the universal design strategy implemented in the device is successful.

Conclusion

The results of the study, showed that the assistive device developed will make the visit of a hearing impaired person to the museum more informative and enjoyable. Universal design of the device makes it suitable for use by persons with normal hearing also. The availability of the device in any museum will make it accessible to persons with hearing impairment and thereby helps in overcoming the acoustic barriers. Affordability and maintenance is taken care of in the indigenous design. The field trials established the efficacy of the device across different types of hearing aids as well as for persons with different degrees of hearing loss.

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Appendix I

Assistive device for museum access to Persons with hearing impairment

Questionnaire for field trail

Date: Venue of trails:

Name, Address & Contact No:

1. Connectivity between handset and server : Always connected/getting disconnected in between
2. Response from the server towards intermediate request by the handset : Immediate response/delayed response/ no response
3. Intelligibility of description heard through handset headphone : Always intelligible/ sometimes intelligible/ not intelligible
4. Intelligibility of description heard through neck loop coupling with hearing aid : Always intelligible/ sometimes intelligible/ not intelligible
5. Battery backup of the handheld unit : One hour/ two hours/ three hours

- Respondent for field trail: museum visitors with hearing impairment.
- Time given for respondents: one day during visit of the respondent to the museum.
- Cadre of people participating in the field trail: all museum visitors with hearing impairment.

Appendix II

श्रवण क्षतिग्रस्त व्यक्तियों के संग्रहालय अभिगमन हेतु सहायक उपकरण

क्षेत्र परीक्षण हेतु प्रश्नावली

दिनांक : जाँचने की जगह :

नाम, पता एवं संपर्क संख्या :

१.	सर्वर एवं हैंड्सेट में संयोजकता	: हमेशा संपर्क में / बीच-बीच मे बाधित
२.	हैंड्सेट के मध्यवर्ती मांग पर सर्वर की प्रतिक्रिया	: तात्कालिक प्रतिक्रिया / विलंबित / प्रतिक्रिया नही ।
३.	हैंड्सेट हेड्फोन के द्वारा सुने गये विवरण की बोधगम्यता	: हमेशा बोधगम्य / कभी-कभी बोधगम्य / अबोधगम्य
४.	श्रवण यंत्र के साथ नेक लूप कपलिंग के द्वारा सुने गये विवरण की बोधगम्यता	: हमेशा बोधगम्य / कभी-कभी बोधगम्य / अबोधगम्य
५.	हैंड्हेल्ड ईकाई का बैटरी बैकअप	: एक दौर / दो दौर / तीन दौर

Appendix III

ಶ್ರವಣ ದೋಷವುಳ್ಳ ವ್ಯಕ್ತಿಗಳ
ಸಂಗ್ರಾಲಯ ಪ್ರವೇಶಕ್ಕೆ ಸಹಾಯಕ ಸಾಧನ

ದಿನಾಂಕ: ಸ್ಥಳ:

ಹೆಸರು, ವಿಳಾಸ, ದೂರವಾಣಿ:

೧. ಹ್ಯಾಂಡ್ಸೆಟ್ ಮತ್ತು ಸರ್ವರ್ ನಡುವಿನ ಸಂಪರ್ಕ :
ತಡೆರಹಿತ ಸಂಪರ್ಕ/ ಆಗಾಗ್ಗೆ ಸಂಪರ್ಕ ತುಂಡಾಗುವುದು

೨. ಹ್ಯಾಂಡ್ಸೆಟ್ ವಿನಂತಿಗೆ ಸರ್ವರ್ ಪ್ರತಿಕ್ರಿಯೆ :
ತಕ್ಷಣದ ಪ್ರತಿಕ್ರಿಯೆ/ತಡವಾದ ಪ್ರತಿಕ್ರಿಯೆ/ಪ್ರತಿಕ್ರಿಯೆ ಇಲ್ಲ

೩. ಹ್ಯಾಂಡ್ಸೆಟ್ ಹೆಡ್ಫೋನಿಂದ ತಿಳಿಯುವ ವಿವರಣೆ :
ಯಾವಾಗಲು ಗ್ರಹಿಸಬಹುದು/ ಕೆಲವೊಮ್ಮೆ ಗ್ರಹಿಸಬಹುದು/
ಗ್ರಹಿಸಲು ಸಾಧ್ಯವಿಲ್ಲ.

೪. ನೆಕ್ ಲೂಪ್ನೊಂದಿಗೆ ಶ್ರವಣ ಸಾಧನದಿಂದ ತಿಳಿಯುವ ವಿವರಣೆ :
ಯಾವಾಗಲು ಗ್ರಹಿಸಬಹುದು/ ಕೆಲವೊಮ್ಮೆ ಗ್ರಹಿಸಬಹುದು/
ಗ್ರಹಿಸಲು ಸಾಧ್ಯವಿಲ್ಲ.

೫. ಹ್ಯಾಂಡ್ ಹೆಲ್ಡ್ ಘಟಕದ ಬ್ಯಾಟರಿ ಬ್ಯಾಕಪ್ :
ಒಂದು ಸರಧಿ/ ಎರಡು ಸರಧಿಗಳು/ ಮೂರು ಸರಧಿಗಳು