Profiling Long-term Outcomes in children with Auditory Brainstem Implant

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Abstract- Auditory Brainstem Implant (ABI) is a bio-electronic device stimulating Cochlear Nucleus directly by-passing the inner ear and auditory nerve. ABI performed routinely in adults and children who are not candidates for CI. There is dearth of research available on documenting the long term outcomes concerning auditory comprehension and speech and language development in children with ABI. The present study focuses on profiling the long term holistic outcomes of ABI implantees. The Aim of the present study is to profile long-term outcomes in children with ABI with the minimum implant age of 3 years and above. This is a retrospective and prospective cohort of 13 children with unilateral ABI (mean age of 4.67 years) were included. The long-term subjective outcomes in various aspects such as auditory perception, auditory discrimination, auditory hearing performance, speech intelligibility and speech and language developmental skills were administered in children with the implant ages ranging from 3.6 to 10 years. The results showed the auditory performance scores were observed to gradually increase as the implantation age increases and also with improving hearing thresholds. Thus this result has highlighted ABI is an effective approach for the improvement of real-life adaptation and for different types of communication which in turn exhibits significant improvement when used over a longer period of time.

Index Terms- Auditory Brainstem Implant (ABI), Auditory perception, Auditory discrimination, Speech intelligibility

I. Introduction

The auditory faculty is the most sophisticated system of sense and is an important sensory system that serves a range of purposes from alertness to delivering information. Loss of hearing could be empowered with technologies such as hearing aids, however hearing restoration is made possible only with the development of hearing implants such as cochlear and auditory brainstem implants. The choice of management is dependent on the degree, cause, and types of hearing loss. The Cochlear implants (CI) have revolutionized for the treatment of individuals with profoundly hearing loss and the important pre-requisite to undergo cochlear implantation is the presence of the cochlear nerve. CI has been contraindicated in some clinical instances such as inner ear anomalies and individuals with absent or deficit cochlear nerve. In such circumstances, the only option to restore hearing is by stimulating the regions beyond the cochlea and the cochlear nerve. Auditory Brainstem Implantation (ABI) is one such remedy to restore hearing for individuals with such condition. "ABI is an extension of the principle of cochlear implants. ABI involves direct stimulation of the secondary neurons of the relay nucleus (cochlear nucleus) in the brainstem" [Nakatomi, Miyawaki, Kin & Saito, 2016]

The basic functional mechanisms of an ABI are similar to those of a cochlear implant (CI). The CI provides electrical stimulation to the spiral ganglion neurons through an electrode array inserted into the scala tympani whereas, in ABI, the stimulation is given to the surface of the cochlear nucleus by the paddle-shaped electrode array. Both the CI and ABI devices use similar signal processing and the number of electrodes but vary primarily in stimulation location that is the cochlear nerve versus cochlear nucleus. The outcomes of ABI are unpredictable when compared to CI. The variability in outcomes could be attributed to many factors such as age at implantation, type of anomaly, placement of electrode, number of auditory electrodes and non-auditory electrodes, rehabilitation techniques, sound coding strategy. (Colletti 2007) Gradual improvement in awareness of environmental sound, utterances of words and sentences was observed with increase in implant usage. Speech recognition score was observed between Colletti, Carner, Veronese and Liliana Colletti (2005) tumor (T) and non-tumor (NT) condition who were implanted with ABI and the result revealed non-tumor patients had good performance when compared with tumor patients. Reduction in performance with ABI was seen in patients with neuropathy, cochlear malformations, and neurologic disorders (Colletti et al, 2005). Matthies et al., (2013) studied speech understanding in patients following implantation of ABI. The audiological performance was assessed using the Sound Effects Recognition Test, Monosyllable-Trochee-Polysyllable test and open-set sentence tests which revealed there were a significant improvement from initial fitting to 12 months follow up. Open-set sentence recognition tests improved from 5% to 37% after 12 months. Revealed Subjective outcomes were determined by using the self-reported questionnaire revealed that patients responded satisfied' to 'very satisfied' with their ABI. Madhav, Sampath Kumar, Vadivu, Natarajan and Kameswaran (2018) have studied 24 children who underwent ABI for a year. Outcomes were measured using 9 (CAP) categorical auditory perception and (SIR) speech intelligibility rating scale which revealed that at 6 months of implant age the average CAP and SIR scores were 2.07 and 1.37 and at 1 year the CAP scores improved to 3.42 and SIR to 2.33 respectively, which depicted gradual improvement in audiological and verbal outcomes.

The aim of the study is to profile the long-term outcomes in children with ABI with the minimum implant age of 3 years and above. It comprises of profiling the progress of the children in auditory and speech performances at various time series of implant ages and to document the subsequent developmental trend in ABI implantees.

METHOD

Subjects included were 13 children with mean age range of 4.67 years and a user of Auditory Brainstem Implant. Participants with any behavioral, motor, or neurological deficits and syndromic conditions were excluded from the study. Informed consent was acquired from the parents of the children. The long-term subjective outcomes in various aspects such as auditory perception, auditory discrimination, auditory hearing performance, speech intelligibility and speech and language developmental skills were obtained in children with the implant age ranging from 3.6 to 10 years. The progress of a child's auditory and speech performances were obtained at different intervals from baseline (immediately after switch on), 6 months, 1 year, 1.6 years, 2 years, 3years and till the current implant age of each participant. The measures used for the prediction of outcomes are as follows,

Table 1. Subjective outcome measures

Outcome measures	*Skills assessed*
Aided audiometry (AA)	Hearing performance
SDS (Speech Discrimination Scores)	Auditory Discrimination
MAIS (Meaningful Auditory Integration Scale)	Auditory Discrimination
MUSS (Meaningful Use of Speech Scale)	Speech
CAP (Categories of Auditory Perception)	Auditory perception
GASP(Glendonald Auditory Screening Procedure)	Auditory comprehension
COT (Common Object Token Test)	Auditory comprehension
SIR (Speech Intelligibility Rating)	Speech
E-Reels (Extended Receptive and Expressive Language Scale)	Language

Descriptive statistics were carried out to profile the auditory, speech and language outcomes in ABI implantees at various implant ages. Inferential statistics were done to determine the significance across the intervals. Friedman test was carried out to find the significant difference between mean rank scores of all the outcome measures across the time plots.

II. RESULTS

Result revealed that the above mentioned tests have been tabulated in table 1.There was an appreciable differences seen in mean scores for all the tests across different time series.

	MAIS		*MUSS*		*CAP*		*SIR*		*COT*		*GASP*		*AA*	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Baseline	2.53	2.75	4.61	3.27	1.00	.57	1.07	.27	0.00	0.00	0.00	0.00	79.73	7.81
6 months	12.53	6.46	9.07	5.13	2.69	1.37	1.69	1.03	0.46	1.66	0.07	0.27	61.14	14.61
1 year	21.84	8.47	15.00	7.33	4.07	1.18	2.30	0.85	7.38	11.57	0.30	0.85	52.43	11.63
1.6 years	24.76	7.97	17.61	7.46	4.23	1.09	2.53	0.77	13.15	11.05	0.38	1.12	49.48	9.23
2years	26.07	7.44	20.38	7.92	4.30	0.85	2.76	0.92	18.07	9.32	1.92	1.25	52.94	17.34
3 years	28.15	6.99	24.07	7.57	4.23	0.83	2.84	0.89	22.92	10.96	2.61	1.26	48.97	18.03
Current implant age	30.61	7.14	30.69	6.51	4.76	1.23	3.07	1.037	28.84	11.14	4.07	1.49	44.61	15.41

Table 1. Mean and SD of Subjective outcomes across various Implant ages.

Inferential statistics include non-parametric friedman test to analyze the auditory and speech performance tests across time series of implant ages such as from baseline, 6 months, 1 year, 1.6 years, 2 years, 3years and The current implant age which revealed significant differences amongst all the tests and implant ages which is tabulated in the table 2 below

Table 2 Comparison of outcome measures across various Implant ages

Tests	*Chi square*	*Significance value*
MAIS	73.918	0.000*
MUSS	75.958	0.000*
CAP	64.317	0.000*
SIR	63.542	0.000*
COT	73.253	0.000*
GASP	72.122	0.000*
AA	38.680	0.000*

Friedman non-parametric test was carried out to determine the significance between mean rank and implant ages which revealed, MAIS scores for all the 13 participants from baseline till the current implant age were highly significant ($p<0.05$). Figure 1 depicts MAIS scores in various time plots. For S1, S2, S6, S8, S10, S12 the scores were gradually increasing over implant use. After 1.6 to 2 years of implant use the scores were plateaued. For S5, S7, S9, S11 there was a steady improvement in performance scores after 1.6 years of implant use the scores was observed to be stagnant then the scores begun to rise after 3 years. For S3, S4, S13 even though they had less impressive outcome over performance scores there was a significant improvement observed with increasing implant usage

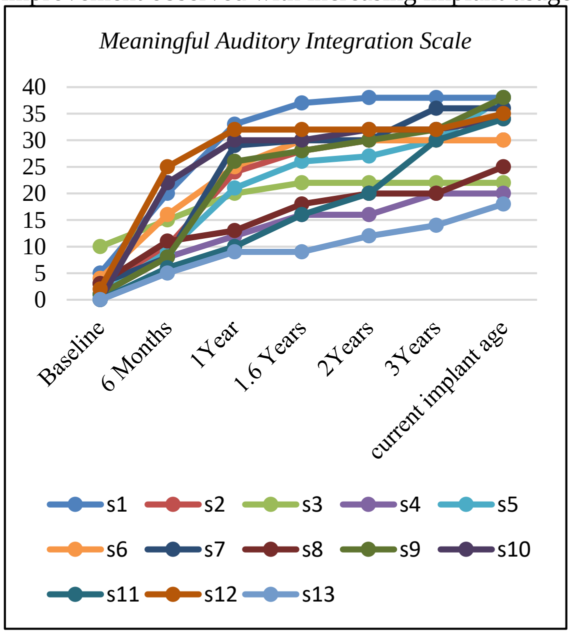

Figure 1. **Meaningful Auditory Integration Scale scores.**

The performance of MUSS indicates improvement in the speech performance with device use. Figure 2 indicates the MUSS scores across various time plots. For S3 and S5 there was a steady improvement in performance scores were observed beyond 2 years of implant use there was an abrupt increase in performance was noted. Similarly, for S8, S9, S10, S11, S12 was observed to have a rise from plateaued scores beyond 3 years of implant use. S1, S2, S6, S7 observed to have a gradual rise in outcomes. S4, S13 indicate a improvement over usage of the device but it is fairly appreciable.

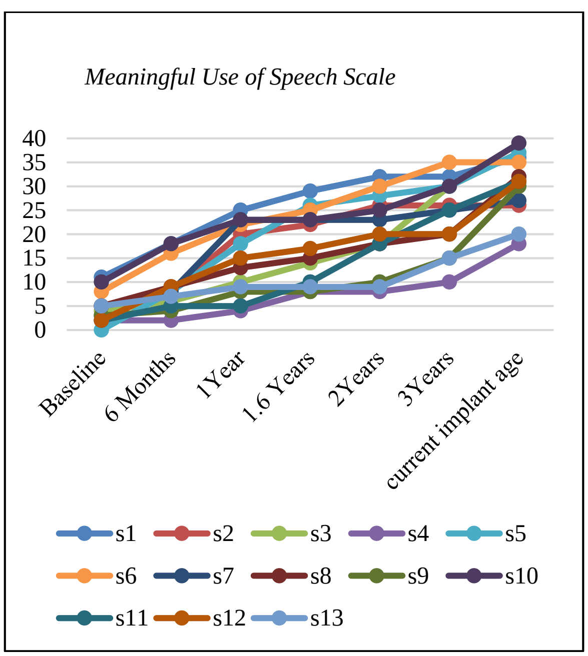

***Figure 2*. Meaningful Use of Speech Scale scores.**

CAP was administered and a significant development was observed among all subjects. Figure 3 indicate CAP scores in various time plots. For subjects S2, S3, S4, S6, S7, S8, S9, S11 the scores post 1 year of implantation was observed to be flat response or no evident improvement. For subjects S6 and S12, there was an abrupt rise from score 1 to score 5 (i.e. Awareness of environmental sounds to common phrases, no lip-reading) when compared to baseline. For subjects S1 and S10 there was an increase in scores till 6 and after 3years of implant use, there was an evident increase in performance. For S13 up to 1.6 years, the score was 1 (i.e. Awareness of environmental sounds) then at 4 years of implant age the score was observed to be 3 (i.e. Identification of environmental sounds)

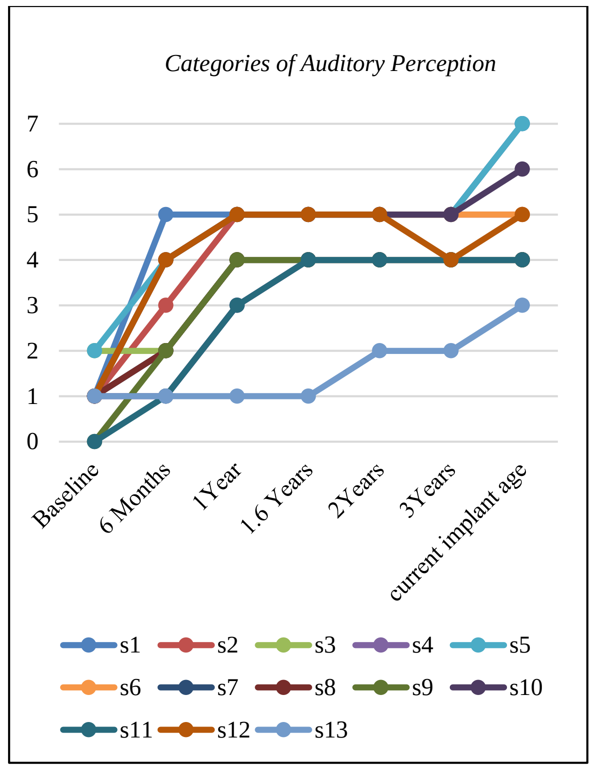

***Figure 3*. Categories of Auditory Perception scores.**

The SIR scores were scattered among subjects. The overall speech intelligibility for all the subjects was limited with the score of 2 (i.e. Response to speech sounds) until one year of implant age beyond which there was a increase in speech performance. Figure 4 indicates SIR scores. For subjects S3, S7, S11, S13 less intelligibility scores were obtained when compared with other subjects.

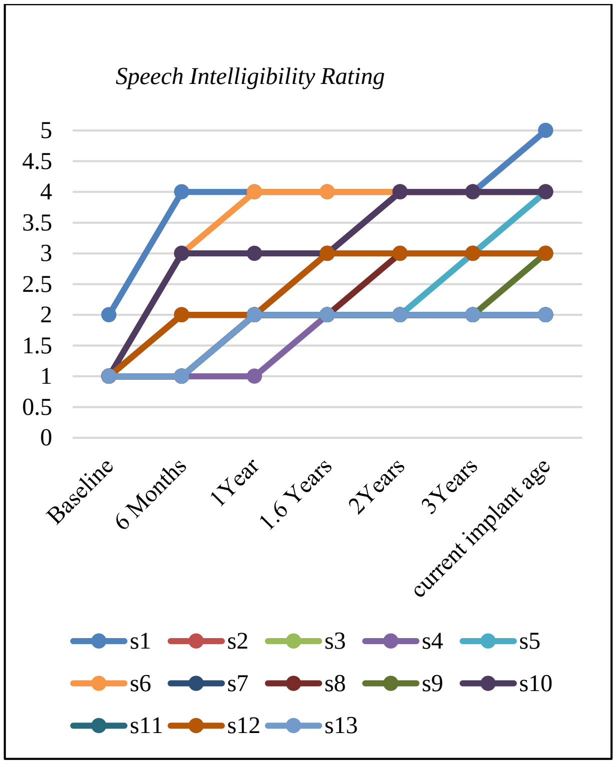

Figure 4. **Speech Intelligibility Rating scores.**

The overall performance of COT was observed to be limited in all the subjects. Subjects exhibit difficulty in identifying the sentences that is presented to them, which indicates limited listening abilities for understanding the sentences. On observation, increase in implant age indicates an evident increase in performance. For subjects S1, S5, S10, S6, S12 the COT scores exceeded 50% out of the total score.

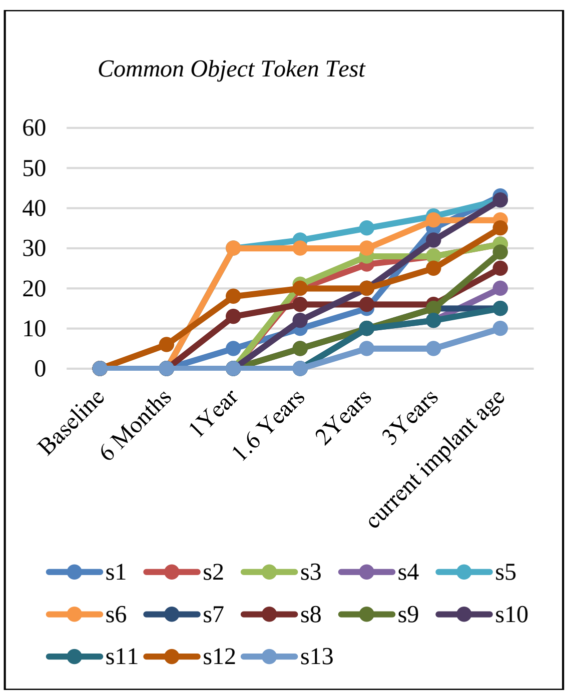

Figure 5. Common Object Token Test scores.

GASP is an open set standardized test that contains 10 questions. For subjects S2, S3, S4, S5, S6, S8, S9, S11 and S12 only after 2 years of implant use they were able to respond to the few questions. Beyond 2years of implant age there was a slow and steady increase in performance were noticed. For S7 & S13 Less appreciable scores i.e. 2 out of 10 points were obtained and they were able to respond to the open set questions only after 2 years of implant use. Figure 6 indicates the GASP scores.

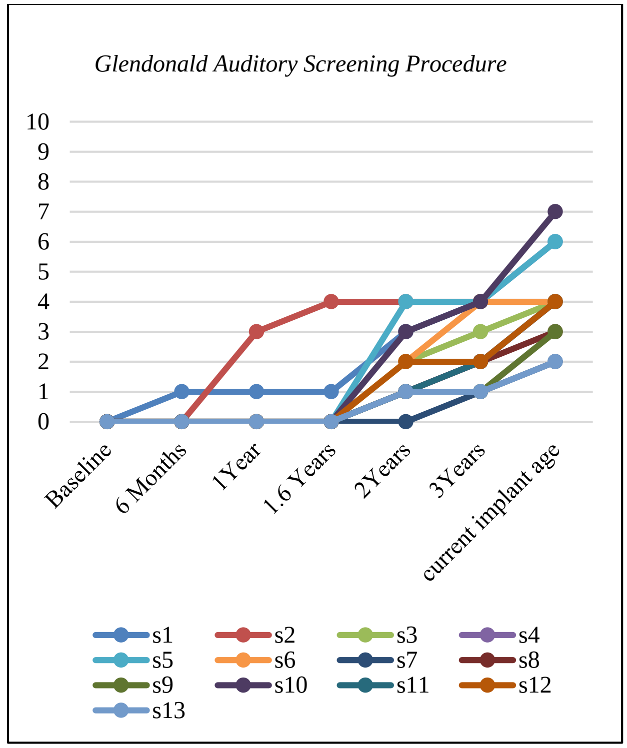

Figure 6. **Glendonald Auditory Screening Procedure scores.**

Aided audiometry measures the minimum threshold level at which the participants respond to the auditory stimuli. Overall auditory performances were observed to be highly significant for all the participants from baseline till the current implantation age of the children. There was a steady improvement in aided audiometry thresholds with increase in implant age. Figure 7 indicates the improvement in aided thresholds.

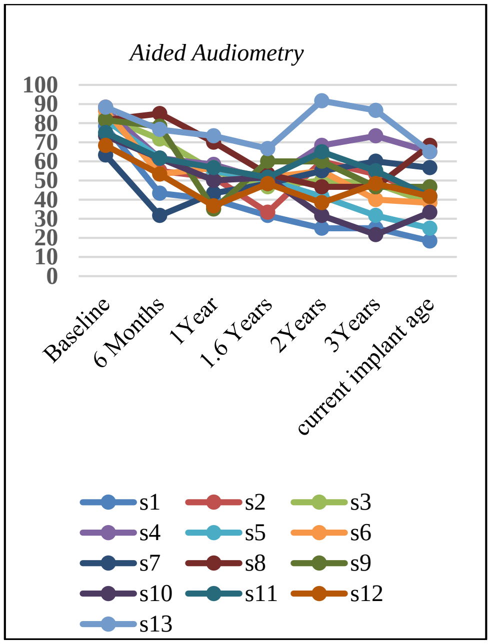

***Figure 7*. Aided audiometric thresholds**

Speech discrimination scores (closed set) were assessed in all the individuals at current implant ages. subjects S1, S5, S6, S9 & S10 scored above 50 % in speech discrimination performance scores with increase in implant age varying from 3.6 to 10 years. Whereas the other subjects scores were noted to be below or equal to 50 %. The speech and language skills of all the participants revealed delayed receptive and expressive language skills. Even though there was a gradual improvement of speech and language skills with increase in implant age, the performance is same as the baseline age.

III. DISCUSSION

Holistically, there was a gradual improvement in auditory, speech and language skills on ABI use. S1, S5, S6, S9, S10 were observed to exhibit good performance sores in all the outcomes measures when compared with other subjects. On observation, there was a steady improvement beyond 1 year of implant age until the current implant age. A possible factor for the scattered performance across subjects would be attributed to implant usage.

The results obtained in the present study in accordance with literature by sennaroglu et al 2009, the auditory performance scores in which the MAIS and MUSS performance scores were observed to gradually increase as the implantation age increases. For a few subjects, the scores became plateaued between 1 .6 to 3 years of implant age further there was an abrupt rise in performance scores (Yucel, Aslan, Ozkan&Sennaroglu, 2015. Auditory and listening skills were better when compared to oral communicative skills in all the subjects that is in consensus with a study done by Colletti et al, 2014 where most of the participants within1-year of implant use showed awareness to environmental sounds (cap score 1) and within 3 years of activation, 26.4% were able to understand common phrases without assistant with lip reading (cap score 5) and among the 26.4 %, 13.2% of the children could use the telephone with a known speaker (cap score 7).

In comparison of CAP and SIR with aided thresholds, there was a significant improvement in scores for individuals with better aided threshold. Study done by Sennaroglu et al (2016) revealed a contraindicating result where, participants with better aided threshold exhibit low score in speech intelligibility rating (SIR) scale.

Yucel, Aslan, Ozkan & Sennaroglu (2015) stated that the speech intelligibility of the participants was observed to be poor until 1 year of implant age, which further improved on the increased duration of implant use which is analogous to the current findings on CAP and SIR test performance. One Assumption for their poor speech intelligibility could be reduced frequency resolution skills in ABI recipients.

Friedman (2016) did a study in patients using cochlear implant (CI) in which, GASP exhibit better speech perception only after 2 years of implant age. However, in ABI recipients, the temporal and spectral resolution skills were not determined when compared to CI. These findings may attribute to poor speech perception in ABI recipients.

Sennaroglu et al, (2016) stated that with an increase in ABI usage the aided thresholds, auditory and speech performance gets improved. Significantly when the hearing thresholds are better the CAP and SIR scores also improve which is correlated with the current study.

Teagle et al (2017) stated that children with ABI exhibited better receptive language skills and delayed expressive language skills and most of them exhibited delayed language skills, which could be due to slow development of auditory skills in children with ABI that precipitate limited changes in speech production.

IV. CONCLUSION

This work has highlighted that ABI is an effective approach for individuals with inner ear anomalies and cochlear nerve deficit to improve their communication and performance. It is evident that the overall auditory and speech performance increases with increase in implant age. However, few subjects in the present study was observed to have less improvement in their listening, auditory and oral communicative skills. This is attributed to several factors such as family support, socioeconomic status, cognitive skills of the child, other attention/behavioral issues, duration of deafness, course of habilitation, age of implantation, periodic maping and follow up for audiological and speech & language evaluation, child's learning environment at school set up, educational placement of the child.

Limitation of this study includes, subject size was less. Objective outcomes measures can be administered in order to determine the correlation between subjective and objective outcomes. Detailed speech and language evaluation should be carried out to get more information regarding speech production and speech intelligibility. Multidisciplinary approach is required in pre and post implantation evaluation and follow up. Phonological development must be strengthened in order to improve speech production skills. Also children with ABI requires additional cues such as visual cues to aid them in effective communication.

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