Auditory Functionality and Early Use of Speech in a Group of Pediatric Cochlear Implant Users

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SUMMARY

This study examined auditory functionality and early use of speech in a group of paediatric cochlear implant users. Parents of 33 implanted children from the Universiti Kebangsaan Malaysia Cochlear Implant Program were interviewed using the Meaningful Auditory Integration Scale (MAIS) and the Meaningful Use of Speech Scale (MUSS). In general, higher MAIS scores post-implantation were significantly associated with higher MUSS scores suggesting that those with better functional hearing with the implant were also better in using spontaneous speech to communicate. Multiple regression analyses showed that several time factors significantly correlated with the MAIS scores post-implantation but not with the MUSS.

KEY WORDS:
Cochlear implant, Children, MAIS, MUSS, Parents

INTRODUCTION

Cochlear implant (CI) is a medical technology that has been successful in 'restoring' hearing of individuals with severe to profound sensorineural hearing loss. Pediatric cochlear implantation has resulted in greatly improved auditory performance of congenitally-deaf children that would otherwise being deprived by the limitation of benefits from the use of acoustic hearing aids. In general, the use of cochlear implants in children who are born deaf helps these young children to develop speech and language [1-8]. For example, in a study by Richter *et al* [5] on 106 children with at least 2 years experience with the implant, clear improvements in both speech perception and speech production post-implantation were ascertained ($p<0.001$).

In many studies, speech perception tests have been used to measure the outcome of cochlear implantation. However, in young children, doing speech perception tests are sometimes impossible because of their limited linguistic skills. This is also true for hearing-impaired children with other disabilities[7,9] in which speech perception benefits are difficult to measure with acceptable reliability. As such, parents are commonly interviewed to quantify auditory benefits obtained by their child with the implant and/or hearing aids using structured questionnaires. Two such valid and reliable questionnaires that are commonly used in audiology clinics are the Meaningful Auditory Integration Scale (MAIS)[10] and the Meaningful Use of Speech Scale (MUSS)[11]. A study by Kubo *et al* [12] for example, utilized three parental questionnaires including MAIS and MUSS to evaluate early auditory perception and speech production skills of 68 prelingually deaf CI children.

MAIS is a structured questionnaire for parents that consist of 10 questions which can further be divided into 3 subsections: Questions 1 and 2 are on the child's confidence in using the device, questions 3 to 6 are on awareness to sounds and questions 7 to 10 are on the child's understanding of sounds. For example, question 8 asks whether the child is able to differentiate between father's voice from mother's voice and any other family member's voices. In general, MAIS questionnaire assesses the functional ability of a young child following the fitting of hearing aids or cochlear implants from parents' point of view. As such, it can be used to chart progress in functional hearing performance of a young hearing-impaired child with the hearing aids and/or cochlear implants.

MUSS is also a 10-item questionnaire that examines the child's ability to use speech from parents' perspective. The MUSS questionnaire can also be divided into 3 subsections, in which questions 1 to 3 are on voice control, questions 4 to 8 look into the use of spontaneous speech by the child and questions 9 to 10 examine on the child's ability to change his or her communication strategy to improve clarity and intelligibility of speech. The MUSS was developed as a further attempt to determine the extent to which cochlear implants help profoundly deaf children improve their speech production skills. As with the MAIS questionnaire, MUSS is a validation instrument that can be used to chart the progress in oral communication skills in hearing-impaired children, whether they are using hearing aids and/or cochlear implants.

Universiti Kebangsaan Malaysia (UKM) has been the first in Malaysia to initiate a Cochlear Implant Program, a joint program between the Department of Audiology and Speech Sciences, Faculty of Allied Health Sciences, UKM and the Department of Otorinolaryngology, Faculty of Medicine, UKM. The program started in 1995 with an implantation of a 16-year old Chinese boy with a post-lingual deafness. In 1997, UKM started to implant the first child with a congenital deafness, using the Nucleus 24 cochlear implant system. Up to October 2009, approximately 250 patients have received Nucleus cochlear implants through the program, many of whom are pediatric cases with congenital deafness. In August and September 2008, two of these young patients received their second implant, making them the first two sequential, bilateral cochlear implant users in the country.

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While there have been many cases implanted, lack of reporting on the outcome of cochlear implantation from the UKM CI program is apparent. A wide variety of auditory performance among the pediatric CI users are observed clinically, ranging from those with the inability to develop spoken language despite relatively consistent, long-term CI usage to 'star' performance in which the implanted child develops the ability to speak three main languages used in Malaysia – Malay, English and Mandarin.

The present study reported the auditory functionality and the use of speech in some of these children resulted from the implant usage, as observed by parents using the MAIS and MUSS questionnaires. In addition, anecdotal clinic reports indicate that the scores on the MAIS questionnaire will reach *'plateau'* after two years of implant experience, thus, it is not suitable to be used to quantify performance of children with implant experience longer than two years. This question was also examined in this study. Specifically, the study investigated the following: (i) the ability of a group of congenitally-deafened paediatric cochlear implant users to integrate auditory information perceived through their implants as compared to their conventional hearing aids; (ii) the correlation between the subjects' auditory functional ability and their use of speech; (iii) several predictive factors that could be associated with better auditory functionality skills post-implantation; and (iv) the duration of implant experience that subjects would generally achieve high scores on the MAIS questionnaire.

MATERIALS AND METHODS

Subjects

Parents of 33 congenitally-deafened children, recruited from the UKM CI program participated in this study. The children's implant experience ranged from 3 months to 8 years and 5 months with a mean of 6.4 years and a standard deviation of 2.3 years. With exception of two subjects, all the other children had full electrode insertion. All children were users of the Nucleus 24 and/or Nucleus Freedom cochlear implant system and using the Advanced Combination Encoder (ACE) speech processing strategy. The children had no other disabilities. Subjects' demographic and implant details are given in Table I.

Methodology

This was a cross-sectional study and data were collected between Augusts to December 2006. Parents were interviewed using the Malay version of the MAIS and MUSS questionnaires [13] when they came in to the clinic for implant programming and/or speech therapy sessions. The direct interview was performed after having parents' consent to participate in the study. MAIS questionnaire was conducted for pre- and post-cochlear implantation to enable comparison of scores. As for the MUSS questionnaire, only the post-implant scores were obtained as all children did not have any speech prior to implantation.

For each question in the MAIS and MUSS questionnaires, the score ranged from 0 (never) to 4 (almost always). Thus, a total possible overall score for each of these questionnaires is 40. Additional questions were obtained from parents on their child's hearing aid usage prior to implantation, the amount of quality time that parents spent with their implanted child outside the therapy hours and parents' educational level. For these additional questions, scoring for questions 1 and 2 was based on the following scale: 0 (never), 1 (rarely – less than 2 hours per day), 2 (sometimes – between 2-4 hours per day), 3 (always – between 4-8 hours per day), 4 (almost always – more than 8 hours per day). While for parents' education level, they were categorized into 4 different categories: less than Sijil Pelajaran Malaysia (SPM), SPM/Sijil Tinggi Pelajaran Malaysia (STPM), Diploma/Degree and Postgraduate Degrees. Demographic details such as age at testing, duration of deafness and implant experience were extracted from the clinic records at the Audiology and Speech Sciences Clinic of UKM Jalan Temerloh, Kuala Lumpur and the UKM Medical Centre in Cheras, Kuala Lumpur. Implant data such as speech processing strategy, stimulation rate, number of active electrodes and speech processor used were obtained from the programming software database in both the above-mentioned centres.

RESULTS

MAIS & MUSS scores

Figure 1 shows the boxplots for the overall MAIS scores pre- and post-implantation in percentage. The mean overall score for MAIS with the hearing aids (MAIS_HA) was 4.70% with a standard deviation (SD) of 4.91% while for MAIS with the cochlear implant (MAIS_CI), the mean score was 76.51% with a SD of 19.90%. A paired-t-test showed that the mean score for MAIS_CI was significantly higher than the MAIS_HA [$t(32) = -19.05$, $p<0.001$].

As mentioned earlier, MUSS scores were not measured pre-implantation as all parents reported that their hearing-impaired child did not have any speech when using the hearing aids. As such, only the descriptive statistic results for the MUSS scores post-CI are shown in Table II. It can be seen from this table that the overall MUSS scores ranged from 10 – 100% with a mean score of 61.74 ± 23.79% suggesting the relatively large variability of performance of the children in terms of using their speech, as reported by parents. The lowest mean score was for the subscale communication strategy (53.41 ± 33.70%) indicating the difficulties of these children to improve their communication strategy or to find a different way of relaying the information orally when their speech was not understandable to others.

Correlation analyses between MAIS and MUSS scores

Simple correlation analysis between the overall MAIS_CI and MUSS scores revealed a highly significant result ($r = 0.625$, $p<0.001$) in which the higher the MAIS scores, the higher the MUSS scores. Correlating the MAIS_CI scores with each of the MUSS subsections, namely the voice control (MUSS_V), use of spontaneous speech (MUSS_Sp) and communication strategy (MUSS_CommS), showed the following: for MAIS_CI and MUSS_V, $r = 0.257$, $p = 0.149$; MAIS_CI and MUSS_Sp, $r = 0.697$, $p < 0.001$; MAIS_CI and MUSS_CommS, $r = 0.480$, $p = 0.005$ suggesting the use of spontaneous speech and ability to use different communication strategy significantly associated with higher MAIS_CI scores. Figure 2 illustrates the correlation analyses between MAIS_CI and MUSS scores.

However, when multiple regression analysis was performed to see the true effects of each of these factors in combination, the communication strategy (MUSS_CommS) was no longer a significant factor ($p = 0.397$) while the use of spontaneous speech remained a significant factor ($p<0.001$) [$F(3,29) = 9.846$, $p<0.001$]. The significant regression model to predict MAIS_CI scores based on the MUSS subsections scores was as follow:

MAIS_CI = 63.092 - 0.249 (MUSS_V) + 0.523 (MUSS_Sp) + 0.087 (MUSS_CommS)

Correlations between the MAIS_CI and MUSS scores and several predictive factors

Table III summarizes the results of Fisher tests to correlate between several different independent variables (hearing aid usage prior to implantation, amount of quality time parents spent with their implanted child outside the therapy hours parents' education levels and duration of CI usage/day) and MAIS_CI and MUSS scores as the dependent variables. Fisher test was used as data were categorical. For the purpose of the analyses, the MAIS and MUSS scores were divided into two categories: 0-50%, 51-100% while the independent variables were also categorized into two. For the hearing aid usage, duration of implant usage and amount of time parents spent with their implanted child, data were categorized into less than and more than 4 hours. For parents' education levels, they were divided into SPM/ STPM and Diploma/Degree and higher.

Simple Spearman correlation and multiple regression analyses were also carried out to investigate the associations between the following factors and the MAIS_CI and MUSS scores: age at testing, duration of deafness and implant experience and the results are demonstrated in Table IV.

Age at testing and duration of implant experience were significant factors correlated to the MAIS_CI and MUSS scores when tested using simple Spearman correlation analyses. However, when the regression analysis was performed, only the duration of CI experience remained a significant factor in the regression model for MAIS_CI [$F(3,25) = 6.085$, $p = 0.003$] as shown below:

MAIS_CI = 45.853 + 0.43 (age at testing) + 2.38 (duration of deafness) + 5.447 (duration of CI experience).

For the MUSS scores, multiple regression analysis did not show a significant model [$F(3,25) = 1.745$, $p = 0.183$]. All the three factors tested in this analysis were not significantly affecting the MUSS scores when examined in combination.

iv) MAIS scores and duration of implant experience

To examine whether MAIS reaches the 'ceiling' score after 2 years of implant experience, a quadratic regression function was plotted: $y = 6.89 – 0.21x + 0.002x^2$ in which y = duration of implant experience in years and x = MAIS_CI scores. Using the above regression function, a MAIS score of 90% and above was generally achieved after 4 years of implant experience. Figure 3 shows the scatter plot of the regression function.

DISCUSSION

The study examined the outcome of cochlear implantation in a group of congenitally-deaf children with a cochlear implant as reported by parents. Specifically, it quantified auditory functionality of these children and their use of speech following cochlear implantation using validated parental questionnaires - MAIS and MUSS.

The results provide the evidence that in general, parents reported better auditory performance with the implant as compared to the hearing aids, irrespective of the duration of implant experience or age at testing. The average MAIS score post-implantation was significantly higher than the average MAIS score pre-implantation as shown in Figure 1. This result was expected as the use of CI should allow the users to have more access to sounds compared to acoustic hearing aids. The electrical stimulation used in CI directly stimulates the spiral ganglion cells in the auditory nerves, bypassing the acoustic hearing pathway, before sending the coded information to the brain for processing. On the other hand, in acoustic hearing aids, sounds are transmitted via the 'normal' hearing pathway in which from the outer ear, the sounds will travel through the middle ear and the damaged cochlea before being transmitted to the auditory nerves and up to the brain for processing. The damaged hair cells in the cochlea caused the transmitted information to the auditory nerves being distorted and limited.

About 39% of the overall MUSS scores could be predicted from the overall MAIS scores with the CI as indicated in Figure 2. The fact that the MAIS_CI scores were significantly correlated with the MUSS scores suggest that in general implanted children who were better able to make use of the auditory information perceived from their implants, were better in their speech production skills, in particular using their spontaneous speech. This was found to be the only significant parameter when multiple regression analysis was performed between the overall MAIS_CI scores and the different sub-sections in MUSS. Verbal communication is a critical development domain that allows for optimal future emotional, cognitive and behavioural growth and as such, is the main objective of cochlear implantation in young, deaf children. Table II shows that some of the implanted children achieved 100% scores on MUSS questionnaire suggesting that some parents believed that implant technology had helped their children to be more confident in using verbal or oral speech to communicate with others. Subsection 1 on voice control behaviour for example, probes on *'uses vocalization to attract attention'* (Question 1), *'vocalizes during communicative interactions'* (Question 2) and *'vocalizations vary with content and intent of message'* (Question 3). It was evident from the descriptive statistics shown in Table II that the highest average score in the MUSS subsections was for voice control indicating that cochlear implant technology has helped these severely-to-profoundly deaf children to have more access to sounds. Consequently, this enables them to hear and control their own voice and start using their speech spontaneously to communicate with others, no matter whether they were intelligible speech or not.

Table I: Subjects' demographic and implant details

Subjects	Age at testing (year;mos)	Duration of deafness (years;mos)	Duration of implant experience (years;mos)	Implanted side	Number of active channels	Stimulation rate per channel (Hz)
S1	10;7	3;0	7;7	Right	22	900
S2	5;5	3;5	2;4	Right	15	900
S3	8;5	3;3	5;2	Right	22	1200
S4	4;7	1;2	3;7	Right	22	1200
S5	9;5	2;1	7;4	Right	22	900
S6	6;8	3;7	3;1	Right	22	900
S7	8;6	3;11	5;7	Left	20	900
S8	5;9	4;2	1;8	Right	21	900
S9	5;8	0;9	4;11	Right	22	900
S10	8;0	2;5	5;5	Left	22	900
S11	10;2	4;4	5;3	Left	22	900
S12	12;3	3;10	8;5	Right	22	1200
S13	10;7	3;7	7;0	Right	22	1200
S14	5;6	3;1	2;5	Right	22	1200
S15	5;1	2;4	3;9	Right	22	900
S16	4;6	3;0	1;6	Right	22	900
S17	5;3	4;10	1;5	Right	22	900
S18	5;5	4;0	1;5	Left	20	900
S19	3;11	3;2	0;9	Right	22	2400
S20	5;2	4;0	1;2	Right	22	900
S21	4;4	3;0	1;4	Left	22	1800
S22	6;5	2;6	3;11	Right	22	900
S23	6;4	3;6	2;10	Right	21	900
S24	5;0	2;8	2;4	Left	15	900
S25	6;7	3;10	2;9	Right	22	900
S26	10;0	3;0	7;0	Right	22	900
S27	8;0	4;0	2;4	Right	20	900
S28	3;9	2;6	0;7	Right	21	1200
S29	5;6	2;4	3;2	Left	22	900
S30	4;11	4;1	0;10	Right	20	900
S31	6;10	4;1	2;9	Right	22	900
S32	2;11	2;8	0;3	Right	22	900
S33	5;1	3;4	1;8	Right	22	1200

Table II: Descriptive statistics showing the overall MUSS scores and its subsections (N=33).

MUSS items	Minimum score (%)	Maximum score (%)	Mean score (%)	Standard dev. (%)
Subsection 1: Voice control	16.70	100.00	79.05	22.36
Subsection 2: Spontaneous speech	0.00	100.00	55.27	28.09
Subsection 3: Communication strategy	0.00	100.00	53.41	33.70
Overall scores	10.00	100.00	61.74	23.79

Table III: Fisher test results showing the correlations between MAIS_CI and MUSS scores and several predictive factors investigated.

Independent variables	Fisher test (MAIS_CI)		Fisher test (MUSS)	
	χ^2	p	χ^2	p
Hearing aid usage/day pre-CI	0.012	0.71	NA	NA
Amount of quality time parents spent with their implanted child	6.979	0.01*	3.537	0.06
Parents' education levels	2.591	0.17	0.833	0.34
Duration of CI usage/day	0.263	0.61	0.485	0.49

* p<0.05
NA = not assessed

Table IV: Spearman correlation analyses between age at testing, duration of deafness and duration of implant experience and the overall MAIS_CI and MUSS scores as the dependent variables.

	MAIS_CI	MUSS
Age at testing	r = 0.519**	r = 0.346*
	p = 0.002	p = 0.049
Duration of deafness	r = -0.011	r = 0.053
	p = 0.954	p = 0.785
Duration of CI experience	r = 0.663***	r = 0.409*
	p < 0.001	p = 0.018

* p < 0.05
** p < 0.01
*** p < 0.001

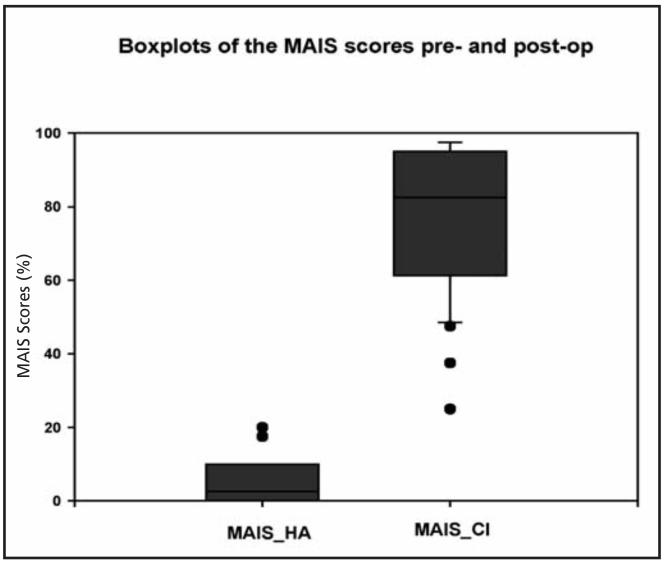

Fig. 1: Boxplots showing the difference in overall MAIS scores pre- (MAIS_HA) and post-operatively (MAIS_CI).

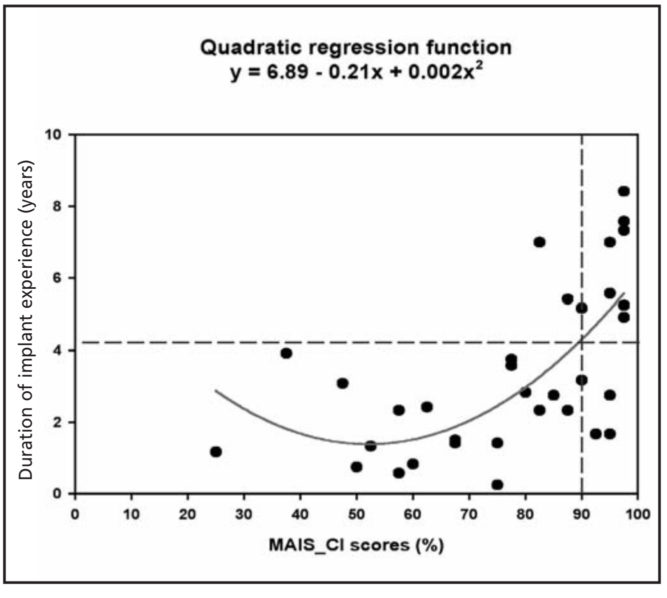

Fig. 3: The quadratic regression function analysis showing a MAIS score of 90% and above was generally achieved after 4 years of implant experience.

Age at testing and duration of implant experience significantly associated with both the MAIS and MUSS scores when examined as individual factors using simple correlation analyses. However, when tested together in multiple regressions, while the CI experience remained a significant factor affecting the MAIS_CI scores, none of these factors was significant with the MUSS scores. It was expected that as a child has more experience in listening through the implant, they would have better functional hearing. Interestingly, this was not a strong enough factor with the MUSS scores when other factors were taken into account. The duration of deafness, which was defined in this study as the length of time since onset of deafness until the CI was switched-on, did not significantly correlated to either the MAIS_CI or MUSS

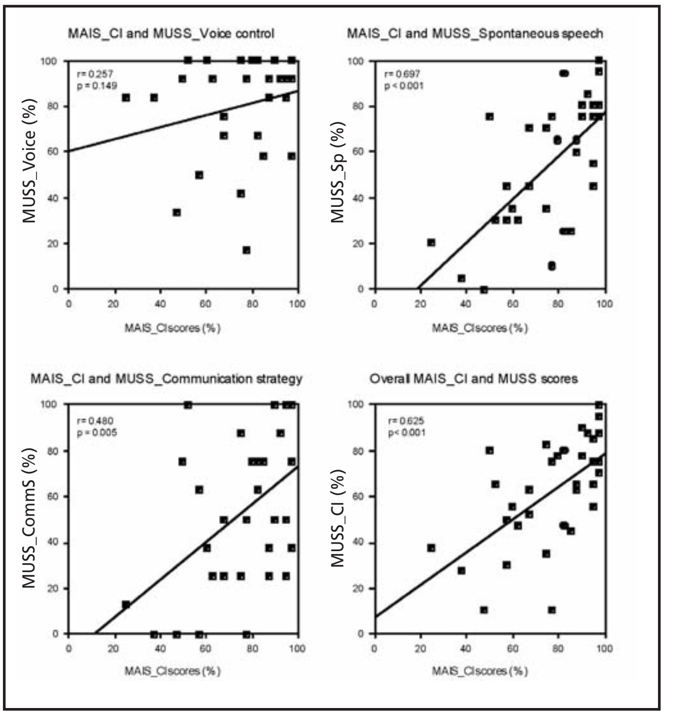

Fig. 2: Correlation analyses between MAIS_CI with each of the MUSS subsections and the overall MUSS scores. The use of spontaneous speech (MUSS_Sp) was the most significant factor correlated with the MAIS_CI scores.

overall scores. This is somewhat surprising as it was expected that earlier implantation should contribute to better outcome, that is, higher MAIS_CI and MUSS scores. These results could have been affected by the relatively small sample size. Alternatively, it could also be better to measure speech perception performance or speech production skills of these children rather than relying on parental reports to examine the effect of auditory deprivation on CI outcome.

Parents' involvement in stimulating a deaf child auditorily has long been recognized as an important factor to enhance auditory performance of the child following hearing aid or cochlear implant fitting. A study by Foy & Mann[14] for example, showed that a teaching focus in the home literacy environment, exposure to reading-related media and parents' active involvement in children's literature were directly associated with phonological awareness and vocabulary increased. DesJardin & Eisenberg [15] reported the positive relation between mothers' quantitative and qualitative linguistic input and receptive and expressive language skills in young children with cochlear implants. The result of this study partly supported the above-mentioned literature in which the amount of quality time that parents spent with their implanted child outside the therapy hours was significantly correlated with higher MAIS scores post implantation. As for the MUSS scores, it showed the same trend even though this factor was not significantly correlated with the MUSS scores. This important finding further support the importance of professionals to work very closely with parents or family members and enhance their involvement in achieving therapy goals to develop speech and language in young children following cochlear implantation.

We did not find in this study that hearing aid usage prior to implantation as a significant predictive factor post-CI, as assessed using MAIS. This could be due to consistent hearing aid usage is one of the pre-requisites to undergo cochlear implantation in the UKM CI program. Most of the UKM implant candidates have to go through the 3-6 months hearing aid trial period in which during this period, audiologists have to ensure among others consistent hearing aid usage by the implant candidates. Reporting of results to the UKM CI team is considered valid if pre-operative speech and audiological assessments are conducted with optimized hearing aid fitting and consistent hearing aid usage of at least 6-8 hours per day. Alternatively, the insignificant finding could also be due to relatively small sample size or bias in parents' reporting.

In order to determine to what extent the MAIS questionnaire can be used as a validation tool in cochlear implant fitting, a quadratic regression analysis was performed. The spread of data as shown in Figure 3 indicates the wide spread of performance among individual cochlear implanted children as reported by parents. In some implant users, they were able to achieve relatively high MAIS scores despite shorter implant experience. However, the trend of data observed in this study suggested that in general, overall MAIS score of at least 90% was achieved after approximately 4 years of implant experience. In other words, MAIS questionnaire is a valid tool to use in assessing auditory functionality of young implanted children up to about 4 years post-CI. For implanted children who achieved this relatively high MAIS score before 4 years of implant usage, their functional performance should be assessed using different or more advanced scales such as the Functioning After Pediatric Cochlear Implantation (FAPCI) [16] instrument, a family-centred communicative performance scale which was constructed based on a conceptual model of functioning established by the World Health Organization.

While the use of parental questionnaires such as MAIS and MUSS is helpful in quantifying early auditory skills among prelingually-deafened pediatric cochlear implant users, and thus, should be used by professionals to chart performance of the implanted children beginning from before the implantation (that is, when using hearing aids) to post-CI, one should be cautious in interpreting the results. A major disadvantage of using parental questionnaires as such is the reliability of the parent/caregiver's responses. It is therefore might be necessary that inter-judge reliability scores be established, for example, with the teacher. Nevertheless, parents/caregivers are the closest individuals to a child that they should be the most reliable people to provide professionals with information on an implanted child's auditory functionality in the real world and their speech and language development skills. In the future, it is also of importance to directly assess the speech perception performance of the implanted children and correlate the results to the MAIS and MUSS. These results would be useful in predicting the outcome of speech tests based on the MAIS or MUSS performance data as some clinics may not have suitable speech test materials to quantify the speech perception performance of these young, implanted children.

CONCLUSIONS

The present study added the evidence that cochlear implants in general significantly improved the hearing ability of children with severe-to-profound congenital deafness, as reported by parents. This study found that these children were better able to make use of the auditory information perceived through their implant as compared to their hearing aids. The study also showed that in general, implanted children who were better able in integrating the auditory information perceived through their implants were also those who were more confident in using their speech to communicate with others as indicated by the significant correlation between the MAIS and MUSS scores post-implantation. The ability to modify communication strategy when talking to others was the most difficult skill to acquire among the tested children as evidenced from the MUSS scores, while voice control subsection was the easiest speech skill to acquire as reported by parents. The amount of time that parents spent with their implanted child, age at testing and duration of implant experience significantly correlated with better auditory integration skills and early use of speech among the tested children. The MAIS parental questionnaire is a useful validation tool to quantify the progress in auditory performance of cochlear implant children when using hearing aids (before the implant) up to approximately 4 years post-implantation, after which, 'ceiling' scores could be obtained. MUSS is also a useful tool to document early use of speech among young, cochlear implant children, as shown in this study.

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