Assessment of early language development in Turkish children with a cochlear implant using the TEDIL test

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Objectives: To analyse language development of children with a cochlear implant (CI) in relation to length of CI use and age at implantation and to examine the suitability of the TEDIL as an assessment tool for measuring early language development in Turkish children.

Methods: A total of 119 children implanted with a CI before 5 years of age were assessed acutely on sound field thresholds, speech recognition thresholds, open-set and closed-set monosyllabic word tests, the TEDIL, categories of auditory performance (CAP), and speech intelligibility rating (SIR). The outcome scores were analysed in relation to length of CI use (3, 4, and 5 years) and age at implantation (<24 months vs. >24 months). The TEDIL scores were compared to all other outcome measures.

Results: Scores significantly increased with CI experience. CAP and SIR were significantly higher in the younger implanted group. No significant difference was observed between the younger and older implanted group on the closed-set and open-set monosyllabic tests and the TEDIL. The TEDIL scores significantly correlated with CAP, SIR, and the closed-set and open-set word scores. The mean TEDIL standard score was close to average.

Conclusions: Performance of CI users improves with increased CI experience. CI users implanted <24 months tend to have better auditory skills and clearer speech than CI users implanted >24 months. CI users implanted between 24 months and 60 months tend to develop language similarly to CI users implanted <24 months. The TEDIL is a suitable tool for assessing early receptive and expressive language development in Turkish children.

Keywords: Cochlear Implantation, Outcomes, Age, Length of use

Introduction

Two language-independent rating scales are commonly used to assess speech perception and speech production in children with cochlear implants (CIs) (Phillips *et al.*, 2009): The categories of auditory performance – CAP and the speech intelligibility rating – SIR. The validity, reliability, and inter-tester reliability of the CAP and SIR have been well documented (Allen *et al.*, 2001; Archbold *et al.*, 1995). Closed-set and Open-set speech tests are also used to measure benefit after cochlear implantation with regard to speech understanding (Caposecco *et al.*, 2012). In addition, language skills have become an essential part of the scientific analysis of CI benefits (Fink *et al.*, 2007). Receptive and expressive language tests with normative data, obtained from typically developing children, have been used to investigate language skills of CI users, such as the Reynell Developmental Language Scales (RDLS) by Reynell and Gruber (1990).

Several studies compared the outcomes of older implanted children with those of younger implanted children to investigate the effect of early implantation on different outcome measures (Holt and Svirsky 2008; Svirsky *et al.*, 2004). A number of studies were conducted to identify key factors affecting outcomes and accounting for the wide variability seen in CI performance, e.g. Geers *et al.* (2009). As very satisfactory outcomes have been achieved in young implanted children, researchers started to compare CI user abilities with those of typically developing children, such as educational and career-related achievements (Duchesne *et al.*, 2009; Geers *et al.*, 2009). Factors affecting outcomes have been found to be performance IQ, parents' education level, gender, socio-economic

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DOI 10.1080/14670100.2017.1299392

status, age at intervention etc. (Cosetti and Waltzman, 2012). Many researchers have concluded that a CI before 2 years of age is beneficial but that there is a large variability in language outcomes even for young implanted children (Castellanos *et al*., 2014). Researchers have begun to investigate outcomes of very young implanted children as compared with young implanted children. Houston and Miyamoto (2010) report little difference in outcomes for children implanted before 1 year and before 2 years but conclude that a CI before 1 year may lead to better vocabulary outcomes. A further finding of outcome studies is that abilities improve with increased length of CI experience (Beadle *et al*., 2005; Stacey *et al*., 2006). However, studies showed that it is difficult for CI users to close the performance gap between themselves and their hearing peers. Yoshinaga-Itano *et al*. (2010) reported that by 7 years of age only 1 or 2 out of 10 CI users (regardless of age at implantation) are likely to close the gap between age-equivalent ability and chronological age. Approximately 50% of CI users after 3–6 years of CI use perform similarly to hearing peers at the word level but less than 50% at the sentence level (Duchesne *et al*., 2009; Geers *et al*., 2009).

The aim of this study is to evaluate auditory performance, speech perception, speech intelligibility, and receptive and expressive language development of children with a CI using fine structure processing (FSP) in relation to age at implantation and length of CI use. The study also examines the suitability of the TEDIL as an assessment tool for measuring early receptive and expressive language development.

Material and methods

Subject demographics

A total of 119 children with profound, prelingual hearing loss (HL), who had received a CI before the age of 5 years and who were followed up and fitted by the MED-EL distributor's audiologists, were included in this study. In Turkey, children with HL can be implanted unilaterally with a CI between ages of 12–24 months if they have a mean HL ≥ 90 dBHL. Children aged 25 months or more can be implanted with a CI if they have a HL ≥ 80 dBHL. The children in this study came from many different implant centres and regions of Turkey. During the 3 years before this study, around 200–250 paediatric MED-EL implants were done per year. All children included in the study had normal inner ear anatomy. Children with obvious additional needs were not included in this study e.g. children with autism or intellectual and developmental disabilities. The audiologists conducting this study were familiar with the CI users, their families, and teachers. The mean age at switch-on of the device was 32.8 months ranging from 13 to 62 months. These CI users were unilaterally implanted with a MED-EL Pulsar^{CI100} and equipped with an OPUS 2 audio processor using FSP. The subjects had no apparent additional impairments and had been using their CIs for 3, 4, or 5 years. The subjects were implanted at different CI centres and were attending various rehabilitation centres across Turkey.

Table 1 TEDIL scoring system

Combined spoken language standard score	
131–165	Very good
121–130	Good
111–120	Above average
90–110	Average
80–89	Below average
70–79	Weak/poor
35–69	Very poor

Test material used

Two-syllable word lists were used to measure speech recognition thresholds (SRTs). Two lists of 10 monosyllables and an open-set monosyllabic word list of 20 words were used to assess speech understanding. The familiarity of words used in all of these tests was carefully tested on hearing 3–4-year-olds. Pictures used in closed-set tests were shown to hearing 3–4-year-olds to check whether they elicited the target word. CAP and SIR were determined. The TEDIL test, which is a Turkish adaptation of the Test of Early Language TELD-3 developed by Hresko, Reid and Hammill (1999), was used to measure receptive and expressive language development. The TEDIL was adapted by Topbaş and Güven in 2013 (Topbaş and Güven, 2013). TEDIL's normative data are based on data collected from a heterogeneous group of 1200 normally developing children aged between 18 months and 8 years. It examines receptive and expressive language and can be used to identify language delay, language disorders, and to plan intervention accordingly. The test comprises verbal instructions given to the child, stimulus objects or pictures which the child is asked to respond to. In this study, TEDIL scores are presented as standard scores. The combined spoken language standard score is compiled from receptive and expressive subtest points. Scoring ranges from 35 to 165 points. A scoring of between 85 and 115 points is considered normal. For the scoring system, see Table 1.

Procedure

Testing was performed at routine follow-up fitting appointments at three different distributor offices with well-equipped audiological suites. Subjects who tired during the first testing session returned for a second session within 1 week of their fitting appointment. First, the functioning of the subject's external device was tested. Then, the appropriateness of the audio processor programme was checked. The electrically elicited stapedial reflex threshold (eSRT) objective fitting method was used to set maximum comfort levels (MCLs) in 92% of cases. Subjects without eSRT were fitted using behavioural methods. Thresholds were either set at 10% of MCL or measured and set at a charge level below the measured threshold. After fitting, implant sound field thresholds (SFTs) were measured at 250, 500, 1, 2, 4, and 6 kHz in a soundproof booth using a GSI 61 audiometer with a calibrated sound field system. Next, each subject's SRT was measured. This test was followed by closed-set monosyllabic word testing. Words were presented through a speaker at 0° azimuth at 65 dBHL. Only subjects scoring 80% or more went on to open-set monosyllabic word testing. Finally, the subjects' receptive and expressive language skills were evaluated using the TEDIL test. CAP and SIR scores were rated after consultation with the children's parents and teachers. If it was not clear in which CAP or SIR category to place a child, they were observed in a specific listening situation, e.g. while talking on the phone, and then categorized.

An informed consent form was signed by each parent before their child's participation in the study.

Statistical analysis

The non-parametric Mann–Whitney *U*-test was used to examine differences in performance in relation to the length of CI use (=device experience), to compare performance between subjects aged ≤24 months at implantation and subjects aged >24 months at implantation, and to analyse performance of these two age groups in relation to the length of CI use.

Pearson's correlation coefficient was used to investigate the relationship between the TEDIL combined standard score and the other outcome measures. Spearman' Rho correlation coefficient was used to examine the relationship between the TEDIL combined standard score and CAP and SIR.

IBM SPSS Statistics 19 (IBM, Armonk, NY, USA) was used for statistical analysis.

Results

Subject demographics

Age at the time of first fitting was 33 months with a range of 13–62 months. Age at the time of testing was 78 months with a range of 47–125 months. Hearing age at the time of testing was 46 months (range 34–69 months).

Thirty nine (32.8%) subjects were implanted at or under the age of 24 months. The mean age of this group at the time of testing was 62 months with a range of 47–83 months; the mean hearing age was 43 months with a range of 34–62 months. Eighty (67.2%) subjects were implanted over the age of 24 months. The mean chronological age of this group at the time of testing was 86 months with a range of 60–124 months; the mean hearing age was 47 months with a range of 35–69 months.

For the length of device experience in the younger and in the older implanted groups, see Table 2.

Table 2 Proportion of length of device experience (>3 years, >4 years, >5 years) in the two different age groups (≤24 months and >24 months)

	3 years CI use	4 years CI use	5 years CI use
≤24 months	64.1%	30.8%	5.1%
>24 months	51.3%	30.0%	18.7%

Results stratified according to device experience

Sixty six (55.5%) subjects had 3 years of CI experience, 36 (30.3%) had 4 years of CI experience, and 17 (14.3%) had 5 years of CI experience.

The combined TEDIL score slightly increased between 3 and 4 years of device experience (0.394) and slightly decreased between 4 and 5 years of device experience (0.356). See Fig. 1.

The percentage of correct answers on the closed-set word test improved with increasing length of CI use. The improvement was significant between 3 years ($n = 66$) and 4 years ($n = 36$) of device experience ($P < 0.001$) and between 3 years and 5 years ($n = 17$) of device experience ($P = 0.001$). No significant improvement was observed between 4 years and 5 years of device experience ($P = 0.660$).

The percentage of correct answers on the open-set word test improved with increasing length of CI use. The improvement was significant between 3 years ($n = 36$) and 5 years ($n = 13$) of device experience ($P = 0.012$). A tendency to significant improvement was observed between 4 years ($n = 28$) and 5 years of device experience ($P = 0.001$). No significant improvement was observed between 3 years and 4 years of device experience ($P = 0.181$).

See Fig. 2 for the results on the closed-set and open-set word tests. Forty-five children could not be tested on open-set because of lack of ability.

No significant correlation was observed between SRTs (dB HL) and length of CI use (Mann–Whitney *U*-test: between 3 years and 4 years: $P = 0.414$; between 3 years and 5 years: $P = 0.709$; between 4 years and 5 years: $P = 0.211$). See Fig. 3.

No significant correlation was observed between mean SFT (dB HL) and length of CI use (Mann–Whitney *U*-test: between 3 years and 4 years: $P = 0.571$; between 3 years and 5 years: $P = 0.399$; between 4 years and 5 years: $P = 0.681$). See Fig. 3.

CAP ratings improved with increasing length of CI use. The improvement was significant between 3

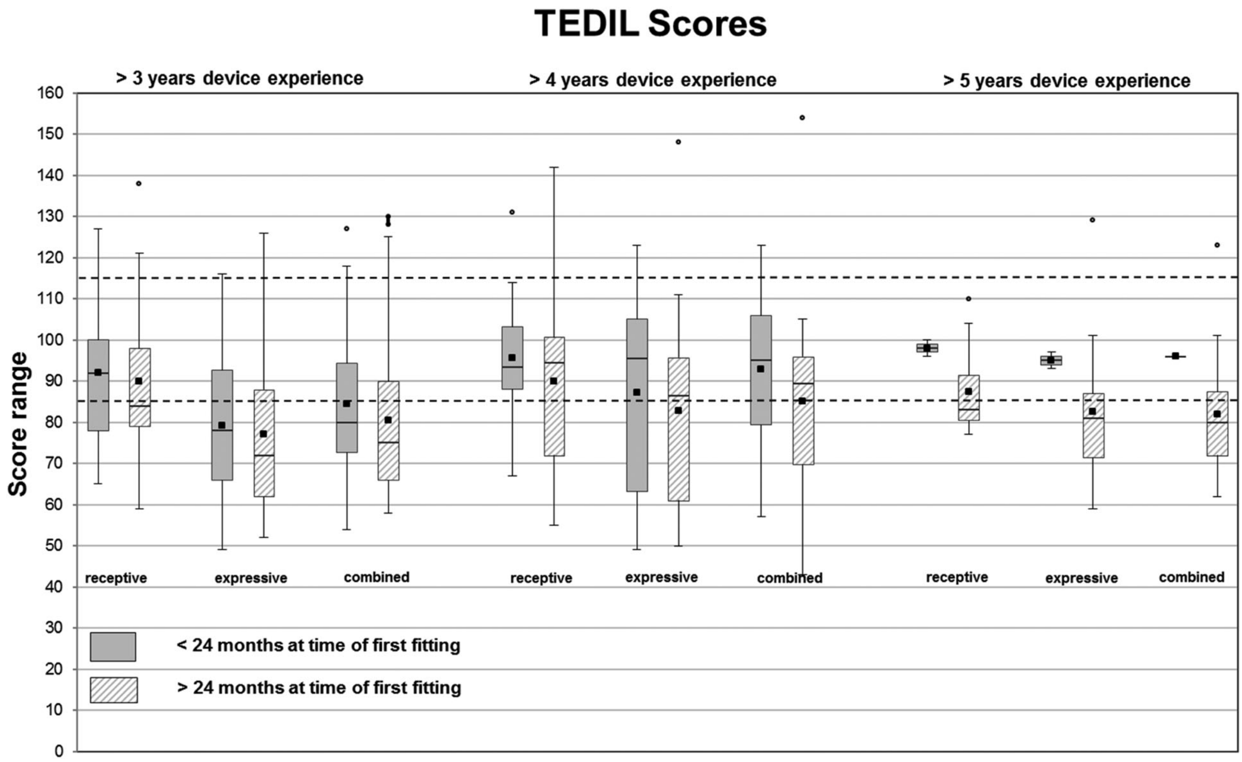

Figure 1 TEDIL receptive standard score, TEDIL expressive standard score, and TEDIL combined standard score stratified for device experience (>3 years, >4 years, >5 years) and age at implantation (<24 months vs. >24 months). Mean values are depicted as black quadrants, median values as horizontal lines. Black dots represent outliers. The dashed lines (85–115 points) represent the area where scores are normal (expected level).

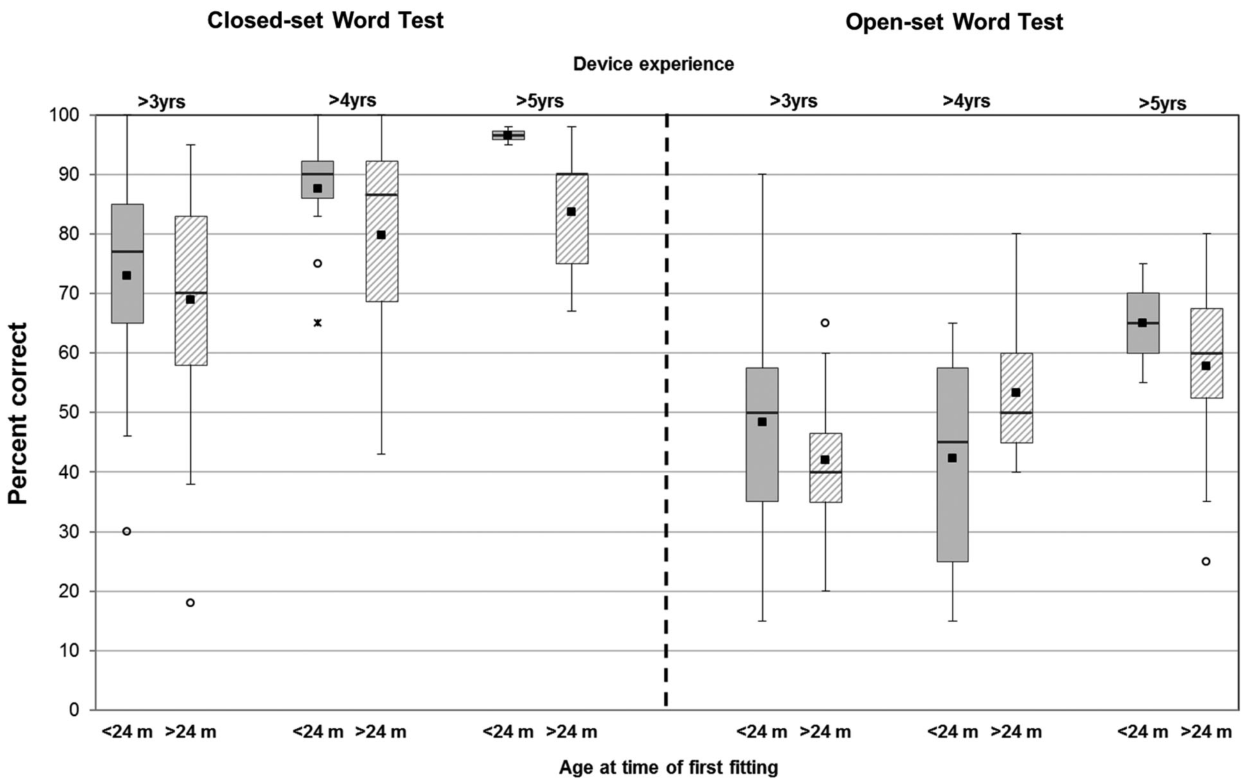

Figure 2 Results on monosyllable closed-set words (%) and monosyllable open-set words (%) stratified according to device experience (>3 years, >4 years, >5 years) and age at implantation (<24 months vs. >24 months). Mean values are shown as black quadrants, median values as horizontal lines. The black circles represent outliers; the black asterisk depicts an extreme outlier.

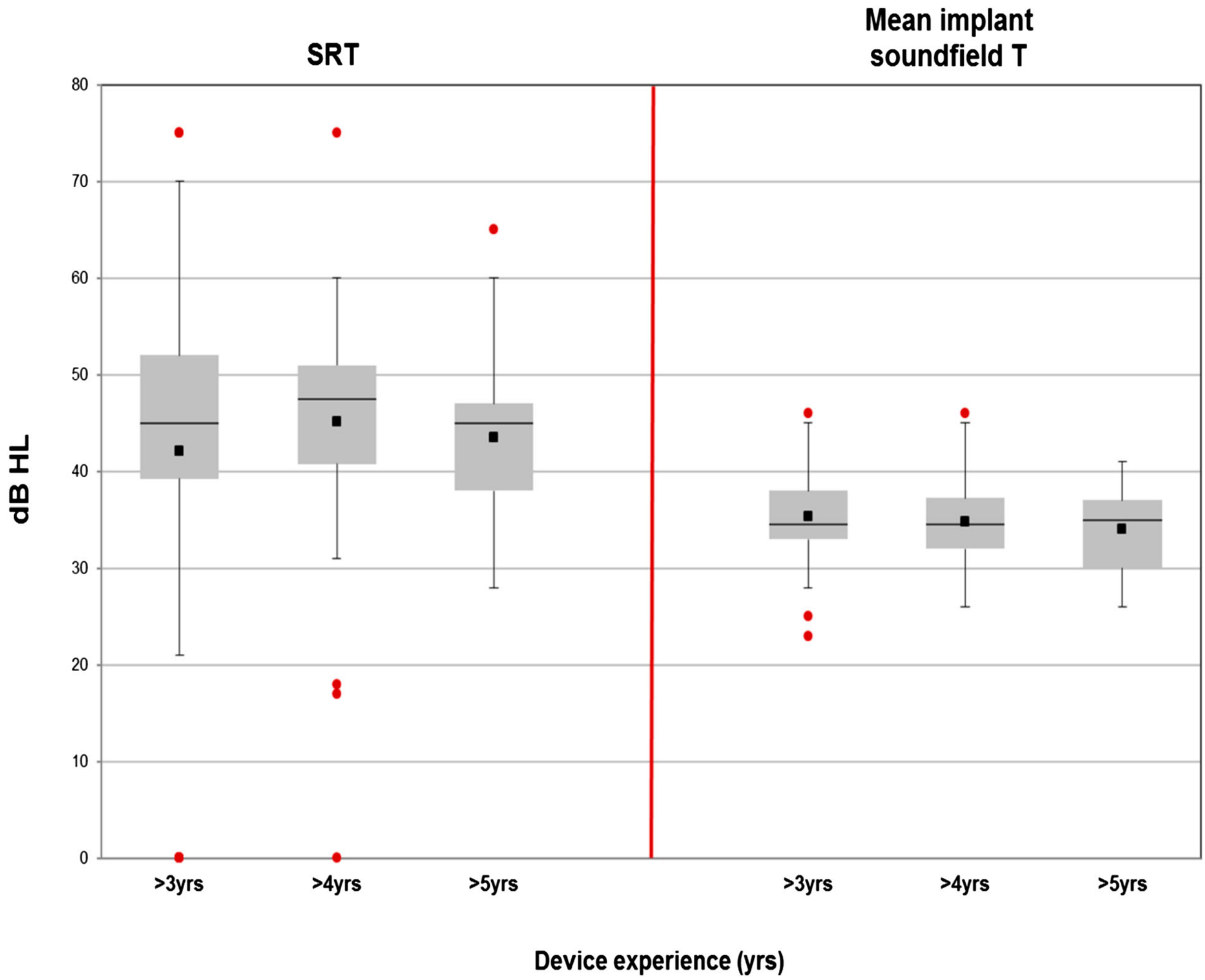

Figure 3 Results on SRT (dB HL) and mean SFT (dB HL) stratified according to device experience (>3 years, >4 years, >5 years). Mean values are shown as black quadrats, median values as horizontal lines. The red dots represent outliers.

years and 4 years of device experience ($P = 0.002$) and between 3 years and 5 years of device experience ($P < 0.001$). No significant improvement was observed between 4 and 5 years of device experience ($P = 0.111$). See Fig. 4.

SIR improved with increasing length of CI use. The improvement was significant between 3 years and 4 years of device experience ($P = 0.008$) and between 3 years and 5 years of device experience ($P = 0.002$). No significant improvement was observed between 4 and 5 years of device experience ($P = 0.213$). See Fig. 5.

Results stratified according to age at implantation (≤24 months vs. >24 months)

Children younger than 24 months at the time of implantation reached higher TEDIL scores compared to children implanted older than 24 months. But according to the results of Mann–Whitney *U*-test, no significant difference was reached between the 2 age groups for the TEDIL receptive standard score ($P = 0.197$) and for the TEDIL expressive standard score ($P = 0.349$). A tendency to a significant difference was found for the TEDIL combined standard score ($P = 0.057$). A significant influence of age at implantation on TEDIL results could not be found in any of the three groups of different device use lengths. There was no significant difference between the two age groups for the children with 3 years of device experience (Mann–Whitney *U*-test: receptive: $P = 0.534$; expressive: $P = 0.433$; standard combined: $P = 0.119$), and the children with 4 years of device experience (receptive: $P = 0.523$; expressive: $P = 0.348$; standard combined: $P = 0.229$). Because of the small n in the group ≤24 months with >5 years of device experience, no age-stratified comparison analysis was performed.

Children younger than 24 months at the time of implantation reached higher scores on closed-set words compared to children older than 24 months, but this difference was not significant (Mann–Whitney *U*-test: $P = 0.313$). Children older than 24 months at the time of implantation reached higher scores on open-set words compared to children younger than 24 months, but this difference was not significant ($P = 0.587$). A significant influence of age

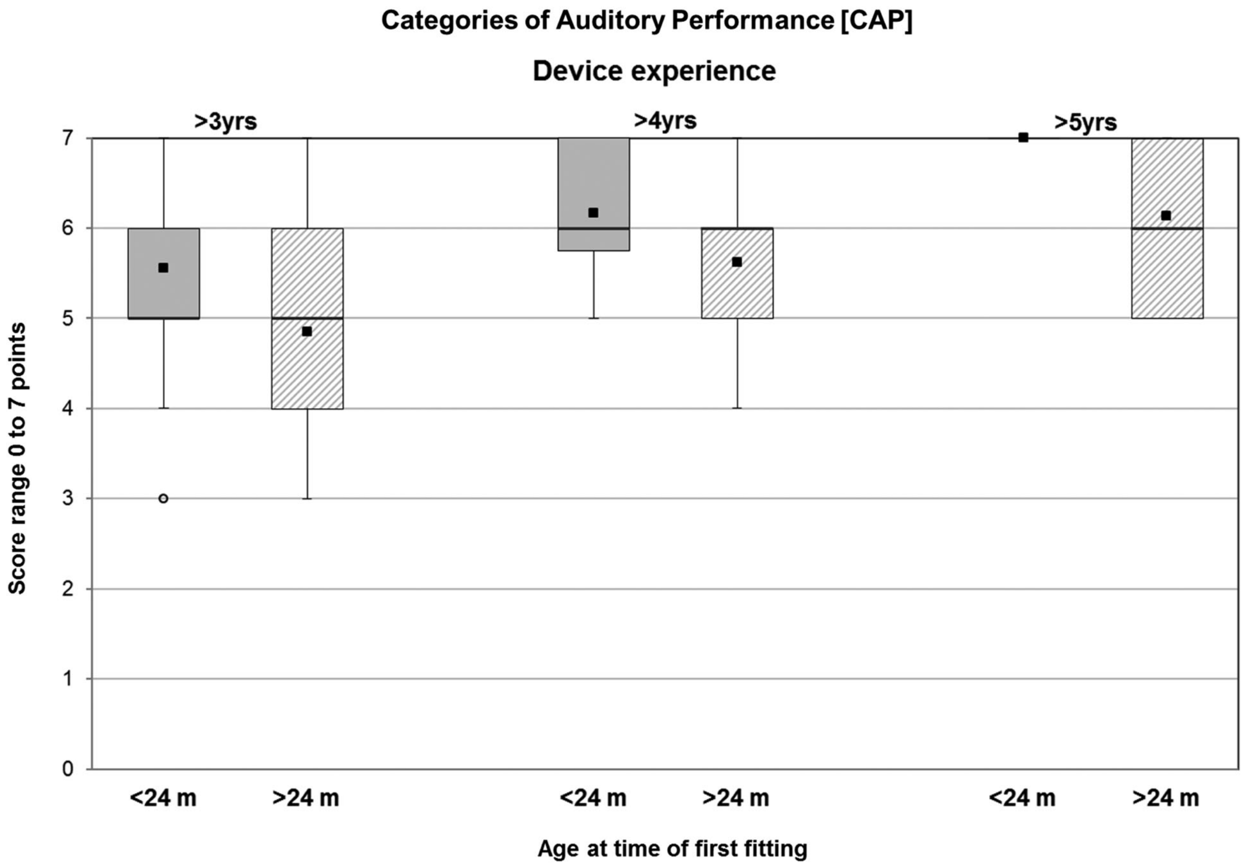

Figure 4 Results on CAP test (range 0–7 points) stratified according to device experience (>3 years, >4 years, >5 years) and age at implantation (<24 months vs. >24 months). Mean values are shown as black quadrants, median values as horizontal lines. The black circle represents an outlier.

at implantation on word test results could not be found in any of the three groups of different device use lengths. There was no significant difference between the two age groups for the children with 3 years of device experience (Mann–Whitney *U*-test: closed-set words: $P = 0.393$; open-set words: $P = 0.414$), and the children with 4 years of device experience (closed-set words: $P = 0.246$; open-set words: $P = 0.226$).

Children younger than 24 months at the time of implantation had poorer SRTs and SFTs compared to children older than 24 months. But according to the results of Mann–Whitney *U*-test, the difference between the two age groups was not significant for both tests (SRT: $P = 0.116$; SFT: $P = 0.111$). Length of CI use did not have a significant influence on SRT and mean SFTs when stratified for age. There was no significant difference between the two age groups for the children with 3 years of device experience (Mann–Whitney *U*-test: SRT: $P = 0.274$; SFT: $P = 0.096$), and the children with 4 years of device experience (SRT: $P = 0.322$; SFT: $P = 0.511$). The *n* for the group of children with 5 years of device experience was too small for statistical comparison with the other two groups.

Children younger than 24 months at the time of implantation reached significantly higher CAP and SIR scores compared to children older than 24 months (Mann–Whitney *U*-test: CAP: $P = 0.025$; SIR: $P = 0.029$). Length of CI use had a significant influence on CAP and SIR results when stratified for age at implantation. A significant difference was found between the two age groups for the children with 3 years of device experience (Mann–Whitney *U*-test: CAP: $P = 0.015$; SIR: $P = 0.014$), but no significant difference was reached for the children with 4 years of device experience (CAP: $P = 0.097$; SIR: $P = 0.285$).

Correlations of the TEDIL combined standard score with the other outcome measures

A significant correlation was found between the TEDIL combined standard score and the closed-set word test ($r = .425$; $P < 0.001$) and the open-set word test ($r = .301$; $P = 0.011$).

No correlation was found between the TEDIL combined standard score and the SRT ($r = -.007$; $P = 0.941$) and the mean SFT ($r = -.151$; $P = 0.110$).

A significant correlation was observed between TEDIL combined standard score and CAP ($r = .717$; $P < 0.001$) and SIR ($r = .722$; $P < 0.001$).

A comparison of the median scores on all measures between the younger and older implanted group is shown in Table 4.

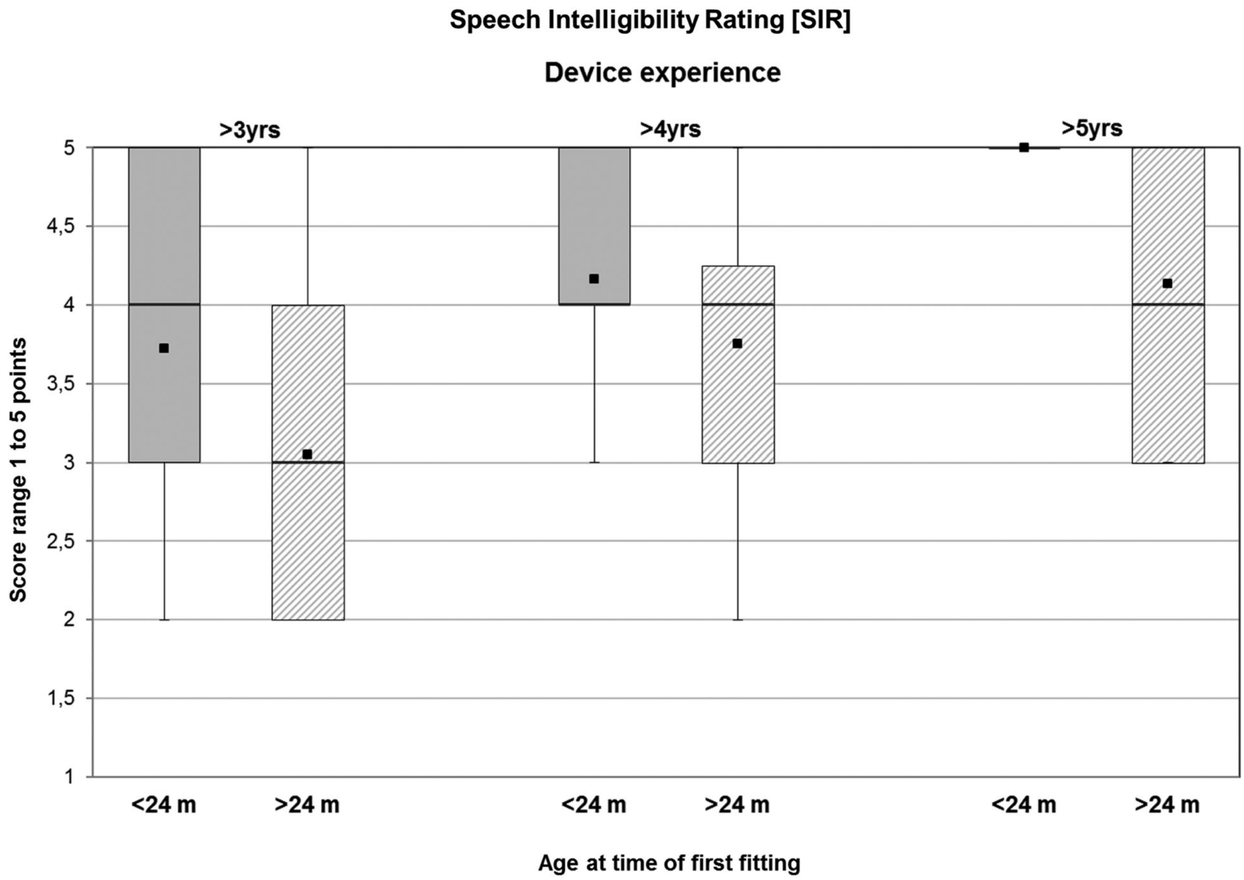

Figure 5 Results on SIR test (range 1–5 points) stratified according to device experience (>3 years, >4 years, >5 years) and age at implantation (<24 months vs. >24 months). Mean values are shown as black quadrats, median values as horizontal lines.

Outcome measure mean scores

For the mean scores in auditory performance, speech perception, speech intelligibility, and language development, see Table 3.

Discussion

Access to sound at an early age allows CI users to develop auditory skills during the sensitive period when their brains are programmed to do this. Better auditory perception, in turn, usually leads to better speech understanding and clearer speech production. This explains why in our study younger implanted children (≤24 months) scored significantly higher on CAP and SIR than later implanted children (>24 months). Furthermore, this supports the findings of a number of previous studies which have shown that early cochlear implantation under the age of 2 years enables children with profound hearing loss to achieve better speech recognition and speech production results than children implanted over the age of 24 months (Anderson *et al.*, 2004; Osberger *et al.*, 2002; Svirsky *et al.*, 2004). In particular, children implanted by 12 months of age are able to acquire auditory skills on par with their hearing peers (Colletti *et al.*, 2012; Leigh *et al.*, 2013; May-Mederake, 2012). Although no statistically significant differences were found between younger and older implanted children in the closed-set and open-set speech test and the TEDIL test, the younger implanted group did score better on every measure. This better performance supports the findings of Tomblin *et al.* (2005) that children who were implanted early in childhood had more rapid language growth rates than children implanted later in childhood. However, several

Table 3 Mean outcomes in auditory performance, speech perception, speech intelligibility, and language development

		SRT dB HL	Mean F/F dB HL	Monosyllabic closed-set words (%)	Monosyllabic open-set words (%)	Monosyllabic open-set syllables (%)	CAP	SIR	TEDIL standard combined score
N	Valid	119	119	119	74	74	119	119	113
	Missing	0	0	0	45	45	0	0	6
Mean		43.18	35.02	76.18	48.89	74.50	5.49	3.61	83.78
Std. Deviation		16.127	4.661	17.055	16.839	10.353	1.080	1.074	19.470

Table 4 Comparison of median values between younger and older implanted groups

Test	≤24 months (median)	>24 months (median)
Closed-set	85	76.5
Open-set word	50	48.5
SRT	43	46
Mean F/F dBHL	34	35
CAP	6	5
SIR	4	3
TEDIL combined Standard score	85	77.5

studies show that children with a CI do not perform as a good as their normal-hearing peers on language tests (Duchesne, 2009; Lund, 2016; Ostojić, 2015). Interestingly, the TEDIL scores in our study slightly increased with 5 years of device experience compared to 3 years of device experience and slightly decreased compared to 4 years of device experience. The discrepancies in language outcomes in children might be due to the fact that many factors other than adequate auditory perception are involved in language learning, such as gender, age at onset of deafness, aetiology, degree of parental involvement, and parents' educational level (Fink *et al*., 2007; Geers, 2006). Similarly, the CAP and SIR ratings did not significantly improve between 4 and 5 years of device experience. The lack of improvement in CAP, SIR, and TEDIL scores between the groups of 4 and 5 years of device experience can probably be ascribed to the reduced number of subjects in the group with 5 years of device use ($n = 17$) compared to the group of 3 years of device use ($n = 66$) and the group of 4 years of device use ($n = 36$). The fact that only two of the 17 CI users with 5 years of device experience were implanted under the age of 24 months may also explain the lack of improvement in scores with increased length of device use. Another reason may be that this is a cross-sectional as opposed to a longitudinal study, which means that different children are in each group. This heterogeneity becomes even more pronounced when the number of subjects is small. Further, SRT did not improve over time, which could be expected considering that SRT represents hearing acuity and thus depends not only on auditory development over time but also on accurate fitting of the audio processor. A similar pattern could be observed with SFT which did not significantly improve over time, either. SFT normally improves in the initial post-implantation phase and then remains stable. However, the closed-set and open-set word test scores significantly improved with device experience and there was a remarkable increase in CAP and SIR scores between 3 and 5 years of device experience.

Altogether, our study showed overall good performance and promising outcomes in all 119 children using FSP. Our results, as shown in Table 3, suggest that paediatric CI users with a mean SFT of 35 dB are likely to have a combined spoken language standard score close to average. The mean TEDIL combined standard score was close to average (83.78), which suggests that children manage to develop average or near-average spoken language ability with 3–5 years of device experience as compared with their hearing peers. Some may find these results surprisingly good, but all users, implanted below age 5 years, were using appropriate AP programmes as provided by audiologists expert in programming and all parents and teachers were using a natural auditory oral approach for the development of spoken language. Our findings are also consistent with the findings of Ramos *et al*. (2015) who report about similar language scores obtained by children with a CI and normal-hearing children and who confirm that cochlear implantation benefits verbal language development in prelingually deaf children. Considering that no one else has reported on outcomes for such a large cohort of Turkish paediatric CI users before, our findings are of high scientific value.

The TEDIL is one of the first tests designed for assessing early receptive and expressive language development in Turkish language, and this was the first study to check the TEDIL for its suitability as a tool for assessing language development in children with hearing loss. The TEDIL scores obtained in this study showed a significant correlation with the speech perception and speech intelligibility scores but no correlation with SRTs and SFTs. This finding suggests that the TEDIL is suitable for evaluating language development in children with a CI. No significant differences were observed in our study between TEDIL scores obtained in the younger and older implanted group; and no significant correlation was found between the TEDIL scores and length of device experience. We think that longer-term outcomes need to be collected and analysed to see if the supposed advantages of earlier implantation and longer device use can be seen in the receptive and expressive language development at later stages.

Conclusion

Performance of CI users improves with increased CI experience. CI users implanted <24 months tend to have better auditory skills and clearer speech than CI users implanted >24 months. CI users implanted >24 months tend to develop language similarly to CI users implanted <24 months. The TEDIL is a suitable tool for assessing early receptive and expressive language development in Turkish children.

Acknowledgements

The authors thank Ursula Lehner-Mayrhofer (MED-EL Innsbruck, Austria) for medical writing assistance.

Disclaimer statements

Contributors Julie Koşaner - designer of protocol, writer of article, fitting and testing audiologist; Murat Deniz, Hüseyin Deniz and Deniz Uruk - fitting and testing audiologists, compilers of results; Edda Amann - statistician.

Funding None.

Conflicts of interest Julie Koşaner and Edda Amman are both employees of MED-EL and receive monthly salaries.

Ethics approval No ethical approval was sought for this study. All programming of CI's and tests conducted afterwards to check the child's performance with the CI and his or her state of development in listening and speaking were all done as per usual. Each child was seen in his or her usual clinic, and fitting and testing were carried out by the audiologist who usually sees the child. Just the same procedures and tests as always used at fitting sessions and follow-up visits were implemented. Children were fitted and tested according to their normal fitting schedule. Parents read and signed a consent form allowing their child's test results to be used anonymously to establish means of performance in paediatric Turkish CI users.

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