THE UNIVERSITY OF MELBOURNE

How Much do Children Use the Second Implant when They Receive Sequential, Bilateral (Two) Cochlear Implants?

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ABSTRACT

Objective: To examine the patterns of second cochlear implant usage by children and adolescents in the two-year period following the receipt of the second implant.

Design: This is a retrospective study examining the returned diaries (including reports by parents or teachers) of twenty-one children and adolescents who received a sequential second implant for two-year period from year 2004 to 2009, to describe the patterns of usage of devices: first implant, second implant and bilateral implants. The participants received their second implant between 2 years 1 month (2y1m) and 19y3m (median age = 8y11m). The time interval between implant ranged from 6m to 16y8m (median= 5y9m). Diaries of three children with simultaneous bilateral implants aged 9.1mth, 9.3month and 1y9m were included to illustrate any potential differences from sequential bilateral implants.

Results: Results show that the majority of the time (an average of 11 hours per day) participants with sequential implants used both implants together. The average use of the second cochlear implant was on average 21 minutes per day over the 24 months post switch-on compared with the usage of the first implant alone which was 1.3 hours per day. The mean hours of daily use of the second cochlear implant alone did not vary greatly across participants.

Conclusions: The minimal usage of the second cochlear implant alone indicates that more counselling would be required by the clinician to increase its usage in children and adolescents with sequential cochlear implants. The importance of training the new cochlear implant alone should be highlighted in the rehabilitation program, in particular, during the first few months post switch-on of the new implant.

DECLARATION

This is to certify that

i. the thesis comprises only my original work towards the degree of Master of Clinical Audiology,

ii. due acknowledgement has been made in the text to all other material used,

iii. the thesis is less than 6,000 words in length, exclusive of tables, maps, bibliographies and appendices.

Signature: ....

(Cheu Lih AW)

ACKNOWLEDGEMENTS

The author is most grateful to all the children, their parents and teachers, and to all the adolescents for their cooperation in this study. Thanks also dedicated to Dr Julia Sarant (academic supervisor) and Dr Karyn Galvin (project supervisor); Ms Meredith Prain and Ms Kathryn Hughes for assisting in the data collection and Dr Robyn Woodward-Kron.

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INTRODUCTION

There are over 120,000 adults and children with a cochlear implant (CI) worldwide. The function of a CI is to directly stimulate the surviving auditory nerve according to the tonotopic organization along the basilar membrane, bypassing the damaged hair cells in the cochlea (Wilson & Dorman, 2008). The CI can be divided into external devices, which are worn outside the body, and internal surgically implanted devices placed under the skin behind the ear. The external device components include a speech processor and transmitting coil. The internal components (implant) are the electrode array, a receiver stimulator, an antenna and magnet. The speech processor (either body worn or Behind-the-ear, BTE) encodes the acoustic signal and transmits it via radio frequency signal to the internal component through the transmitting coil. The radio frequency signals are then received, decoded and presented as stimuli to the electrical multi-frequency electrode array by the receiver (Katz, 2009).

The first cochlear implant used an induction coil that electrically stimulated the auditory nerve, and was invented by Djourno and Eyriès in Paris in 1957. The success of the first implant was mainly limited to detecting environmental sounds, with poor speech discrimination or voice identification and intonation results. In 1961, the first single electrode was implanted in the cochlea using gold wire by Dr. William House in Los Angeles. He also implanted a single-channel device in a child in the early 1980s. The outcomes were the same as with the induction coil, i.e. no audition-alone speech understanding. Given these limited outcomes, research continued to improve results with electrical stimulation of the cochlea. Through the late 1980s, and early 1990s, there was significant achievement in the development of the electrode array and of further speech processing strategies (Wilson & Dorman, 2008). The first multi-channel CI was developed and implanted in an adult in 1978 and in a child in 1985 by Graeme Clark in Melbourne (Katz, 2009; Spelman, 1999). With the advanced technological development of a sophisticated multichannel electrode array and speech processing strategies, speech comprehension outcomes are now very good. The results are well-documented in both adults (Tyler, Dunn, Witt, & Noble, 2007; Valente, Hosford-Dunn, & Roeser, 2007) and children (Nicholas & Geers, 2003; Sarant, Blamey, Dowell, Clark, & Gibson, 2001; Svirsky, Teoh, & Neuburger, 2004).

The CI has become the treatment of choice for adults and children with severe to profound sensorineural hearing loss. Based on industry data, it was estimated that about 30,000 adults and over 30,000 children in the United States have received CIs (Marcus, 2009). The outcome measurements of CI in prelingual children are different to those of postlingual adults. Unlike adults, children with prelingual hearing loss have had to learn speech and language through the auditory input provided by a CI. Therefore, the outcome measurements in children with CI are not only limited to speech comprehension, but also include other outcomes such as language development, speech intelligibility, academic performance and reading skills (Marschark, Rhoten, & Fabich, 2007; Moog & Geers, 2003; Shu-Chen, Linda, & Tomblin, 2004; Vermeulen et al., 1999).

Many studies have been conducted to measure the performance of children with CI in comparison to their hearing peers. A large variation in speech perception, speech production and language performance has been found (Geers, 2002; Moog & Geers, 2003; Sarant et al. 2001). The factors that have been found to significantly affect speech perception outcomes are the age at first implant, duration of deafness and lower pre-implantation hearing thresholds (better hearing level) (Sarant et al., 2001). Children implanted as early as between 1 to 2 years old have also shown better speech and language development (Nicholas & Geers, 2007; Tait, Nikolopoulos, & Lutman, 2007). Early implantation also implies longer implant use and a higher degree of brain plasticity for speech and language development (Connor, Craig, Raudenbush, Heavner, & Zwolan, 2006). Other factors that contribute towards better post-implantation performance generally, in terms of speech perception, speech production, language and reading, are related to nonverbal intelligence quotient (IQ), smaller family size, a greater number of active electrodes, speech processing strategy, larger dynamic range of hearing, auditory-oral communication mode and female gender (Geers, 2002; Moog & Geers, 2003).

Even though the success of cochlear implants has been documented widely, listening with one implant alone is not as natural as listening with both ears. Binaural hearing (listening with two ears), the normal modality of the auditory system, enables one to localize the sound source and gain enhanced speech understanding in noise. These are distinct advantages over listening just with one ear (monaural hearing). The binaural advantages are derived mainly from the head shadow effect, binaural summation and the binaural squelch effect. The physical advantage of the head provides the head shadow effect, which involves the sound waves diffracting around the head and causing the two ears to perceive the same sound at a different loudness (called the interaural level difference). Louder sound is perceived in the ear close to the sound source, while the softer sound is perceived in the ear further from the sound source. This effect helps in sound localization, particularly with high frequency sounds. Binaural summation refers to when a sound is perceived as being louder when listening with two ears together, rather than one. This effect is due to a process that occurs in the brain. Lastly, the binaural squelch effect occurs when the auditory system centrally combines the separate sound waveforms from each ear to form a better representation of the signal in noise than could occur when listening with only one ear. These binaural effects make speech understanding in noise better for bimaural listeners than monaural (one ear only) listeners (Dillon, 2001).

Binaural hearing can be provided through either fitting the opposite (non-implanted) ear of a unilateral CI recipient with a hearing aid (HA) (i.e. bimodal amplification, CIHA) (Ching, Psarros, Hill, Dillon, & Incerti, 2001; Ching, van Wanrooy, Hill, & Incerti, 2006) or through bilateral CIs (BICI) (Firszt, Reeder, & Skinner, 2008). BICI is an option for those who have no usable hearing in both ears or whose aided speech perception performance with one or two hearing aids (HA) is poorer than would be expected with a CI (Perreau, Tyler, Witt, & Dunn, 2007).

Most studies demonstrate that with bilateral stimulation, both CIHA and BICI provide binaural advantages (Firszt, Reeder, & Skinner, 2008). Numerous comparison studies in adults have shown that BICI provide greater binaural advantages in terms of sound localization and speech perception in noise than bimodal hearing (CIHA) (Firszt et al., 2008), but there are fewer studies with children (Litovsky, Johnstone, & Godar, 2006; Mok, Galvin, Dowell, & McKay, 2007).

There are still issues related to implanting the second ear, which is usually the better ear. One issue of debate is whether or not to "save" the better ear from the risk of destruction by cochlear implantation in order to preserve that ear for future beneficial technology (Perreau et al., 2007). Another issue is whether a second CI will provide sufficient extra benefits to the recipient relative to the cost and rehabilitation efforts needed.

There are two methods of bilateral implantation: sequential and simultaneous. Bilateral sequential CI refers to having a second implant (CI2) either after a period of time, or as a result of a different surgery from the first implant. Bilateral simultaneous CI refers to receiving two CIs concurrently, or in the same surgery (Lustig & Wackym, 2005). Regardless of whether the CIs are sequential or simultaneous, in adults, the greatest benefit of having two CIs is derived from the head shadow effect (associated with sound localization), followed by binaural summation and binaural squelch effects (i.e. binaural unmasking or speech recognition in noise) (Firszt et al., 2008).

It is important to note that the data obtained for adults is not directly comparable to that for children. Many of the studies have been done on bilateral sequential CI in postlingual adults who already had many years of experience with binaural spatial hearing. As mentioned earlier, children usually obtain their implants at a very young age (i.e. 1-2 years old), when their language has not yet developed (Nava et al., 2009). Another factor that differentiates children from adults is the anatomical differences between them. For instance, smaller head size in children would likely reduce the head shadow effect that contributes to binaural advantage in adults, particularly regarding sound localization ability (Mok et al., 2007).

In examining the benefits for children with bilateral CIs, it can be seen that there is a wide variability in outcomes (Galvin, Mok, & Dowell, 2007). As opposed to the advantages found in adults with bilateral CIs, the greatest benefit of having two implants for children is that of the binaural squelch effect on speech perception in noise (Litovsky et al., 2004; Peters, Litovsky, Lake, & Parkinson, 2004; Galvin et al., 2007). The literature also shows that overall, children with a sequential second implant demonstrate little or no benefit in bilateral lateralization or sound localization, although results of a recent study contradict this finding (Steffens et al., 2008). This may be due to the fact that the latter study was done after a longer duration of bilateral CI experience, (2 months to 4 years) whilst the earlier studies were done with children who had only 3 to 13 months of bilateral CI experience.

Children who have received their CI2 at a younger age have been shown to adapt more quickly to the second implant than children who received their second implant older, attaining similar speech understanding ability to their CI1 (Peters et al., 2004; Peters, Litovsky, Parkinson, & Lake, 2007; Wolfe et al., 2007). It is difficult to clarify the effect of age at CI2 on the rate of adaptation to the second implant, however, as the studies quoted above used different age groups, test materials and imbalanced numbers of subjects between groups. It has also been demonstrated that children implanted bilaterally under 6 years of age have better speech recognition in noise

(Scherf et al., 2007). In contrast, another study has shown that speech perception in noise of sequentially implanted children is not affected by age (Wolfe et al., 2007).

One of the factors that causes variation in bilateral implantation outcomes is the time interval between the first and second CIs. Generally, the shorter the duration of the time interval, the better the outcomes of binaural advantage (Steffens et al., 2008). This finding is supported by an electrophysiological study of early auditory evoked responses (Auditory Brainstem Response, ABR) using electrical stimulation to the auditory nerves via implant. In simultaneously implanted children, there is no interaural wave eV latency difference. In contrast, the wave eV is found to be longer in the second implanted ear of children implanted sequentially. The latency in CI2 tends to decrease (i.e. the interaural difference is reduced) with activity-related neuromaturation of the auditory brainstem pathway. This discrepancy is likely to resolve over a year of CI2 use, where there has been a short period of unilateral CI1 use, but not where there has been a long period of unilateral use. This implies that a short time period between implants results in less restricted auditory pathway development in the newly implanted ear (Gordon, Valero, & Papsin, 2007). Conversely, one recent study suggested that binaural sensitivity to electrical stimuli could be obtained in children with late second implantation and longer intervals between implants (Van Deun et al., 2009).

Although CI2 is evidently providing better binaural benefits in children, many factors contributing to outcomes are still unclear. For instance, the binaural squelch effect in children is compromised when the noise is placed near the CI2 (contralateral to the first implant, CI1) (Galvin et al., 2007; Mok et al., 2007). As pointed out in these studies, the other factors affecting outcomes could be pre- and post-implantation factors such as restricted listening experience of the second ear preoperatively, and lack of experience in using the second implant alone. Moreover, the factors that affect outcomes with a unilateral implant as mentioned earlier such as age of first implantation, duration of implant use, degree of hearing loss (Sarant et al., 2001; Geers, 2002; Nicholas & Geers, 2007), would also have an impact on the success of a bilateral sequential implant.

A criticism of almost all of the studies on bilateral sequential CI advantages in children is that they do not provide detailed information about CI2 alone usage and the amount or type of training given using CI2 alone. Many studies also had limited sample sizes and short periods of observation. Given this, no clear conclusion can be drawn regarding the importance of using CI2 alone and later binaural benefits.

Anecdotal reports of CI2- alone usage after 6 months of experience for 9 children who received their CI2 under 4 years of age and 14 older children who received their CI2 when aged over 4 years ranged from zero to four hours per day (Galvin et al., 2007; Galvin, Mok, Dowell, & Briggs, 2008). Those who had zero hours of CI2 usage had either totally rejected their CI2 or were wearing both implants all the time. Most children were reported to prefer wearing both implants on a daily basis rather just the CI2 alone.

Detailed information about CI2 alone use is important to obtain, and would be helpful in providing guidance for parents. Unlike the situation with adults, parents of children with bilateral sequential implants can play a role in encouraging CI2 alone use and can practice with their children in order to train the second ear to listen. Thus, they can help to optimize the overall binaural benefits following the sequential implant.

This study examines the patterns of second cochlear implant usage by children and adolescents in the two-year period following the receipt of the second implant. The data used in this study were collected through the use of a monthly parent report diary. Parent reports have been used by many researchers to obtain data about both performance in areas such as emotional, social, speech and language development in young children (Goodman, 1997; Nott, Cowan, Brown, & Wigglesworth, 2003), as formal testing in these areas with very young children can often provide limited information to researchers or clinicians. Although there is potential for bias in parent or teacher reports on children's behaviour, these reports can still be more useful and informative than formal testing, which may be limited due to young children's inability to concentrate or lack of assessable skills such as language..The results of this study will contribute to a larger study by helping to identify factors influencing success with the second implant.

MATERIALS AND METHODS

Participants

As part of a wider project evaluating the benefits of bilateral implants for children, parents and older child participants were asked to complete a diary of device use and to provide reports of listening abilities with the new implant at the RVEEH/ University of Melbourne Cochlear Implant Clinic. Of the families who volunteered, participants were included if the child had no known significant cognitive delay and, was likely to be able to complete the testing of the wider project. Forty-one diaries were sent out to the participants who had bilateral implants. Of these, 33 were implanted sequentially, and eight were children with simultaneous implants.

Procedures

This retrospective study collated and analysed the data from the returned diaries by children and adolescents for a two-year period following the receipt of second implant (CI2) in years 2004 to 2009. The returned diaries were filled in by adolescent participants and parents of younger participants. In the diaries, the participants or their parents were asked to record the individual (CI1 alone and CI2 alone) and both implants together (CI1 plus CI2) hourly usage in a day and comment on listening experiences or observations.

At the time of analysis (August 2009), all the returned diaries for children and adolescents who had received a second implant were examined. Only returned dairies with legible and complete entries for at least three consecutive months were further analysed; leaving 24 children and adolescents from the original group of 33. Of these 24 participants, three were recipients of a simultaneous bilateral implants were included to illustrate the potential differences from sequential bilateral implants.

Data Analysis

The recorded hours of device use in the diaries were further analysed using Microsoft Excel and Minitab. Using descriptive analysis, the patterns of implant alone use (CI2 or CI1 alone) and use of both implants together (BICI) in children and adolescents over 24 months were assessed. Further, this study also investigated the differences in the patterns of device usage between children and adolescents with sequential and simultaneous CI.

RESULTS

Participant Demographics

Twenty-one participants with sequential bilateral CIs (n=21) with age of CI2 between 2 years 1 month (2y1m) to 19y3m old (median age = 8y11m) were included in this study. The time interval between implants ranged from 6m to 16y8m (median= 5y9m). Children with simultaneous implantation (n=3) were aged 9.1mth, 9.3month and 1y9m when they had their implants.

Diaries

Data for 21 participants with sequential bilateral implants were included in this study. The criteria for inclusion of data in this study were returned diaries and recorded device usage legibly and completely for at least three consecutive months. Figure 1 shows the number of monthly diaries returned by participant post switch-on of their CI2 over 24 months. Most of the participants recorded their device usage in the first eight months. Less than ten participants returned their diaries in the last 12 months. No participant returned their diary at the 24 month point.

Only legible returned dairies of three participants with simultaneous bilateral implants were used after selection. No participant returned their diary in the first month post switch-on of implants. Thus, only data from month 2 to month 24 were analysed. All participants had recorded their device usage at the 8-12 month points, as shown in Figure 2. A lack of writing legibility and unclear language were problems encountered with some of the returned diaries. Where the information in the returned diaries could not be interpreted, diaries were not included. Missing entries in dairies also compromised the amount of data that could be used in this study.

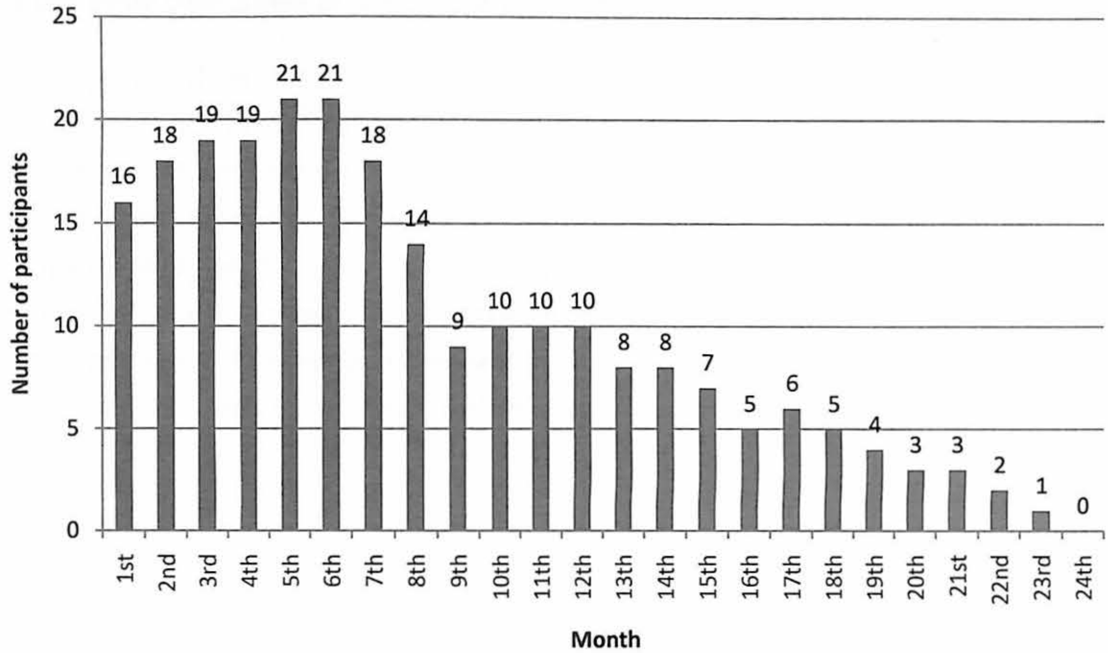

Fig. 1. Number of participants with sequential implants who returned their diaries post switch-on of their CI2 per month.

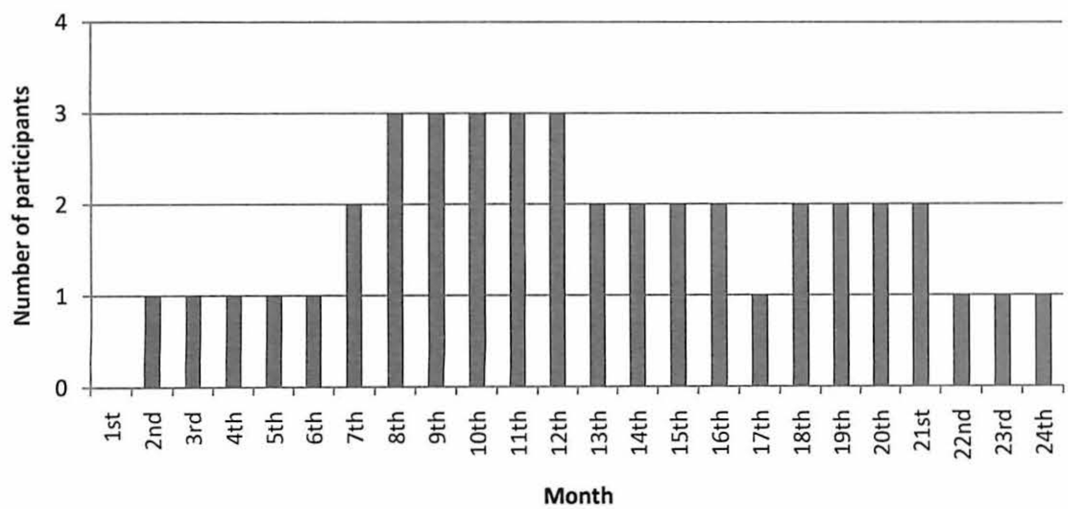

Fig. 2. Number of participants with simultaneous implantation, who returned diaries post switch-on per month.

Average Daily Device Use of Sequential Implantation

Figure 3 shows the median, minimum, and maximum range of the hours of device use per day. Children and adolescents with sequential bilateral implants did not spend very much time using their CI2 alone, the average being 21 minutes per day. The time spent using CI2 alone did not vary a great deal across subjects. The participants used their CI1 alone more than their CI2 alone. On average, CI1 alone usage was 1.3 hours per day. The majority of the time (an average of 11 hours per day) participants used both implants; there was more variation in the amount of bilateral usage (from 39 minutes to 16.2 hours per day).

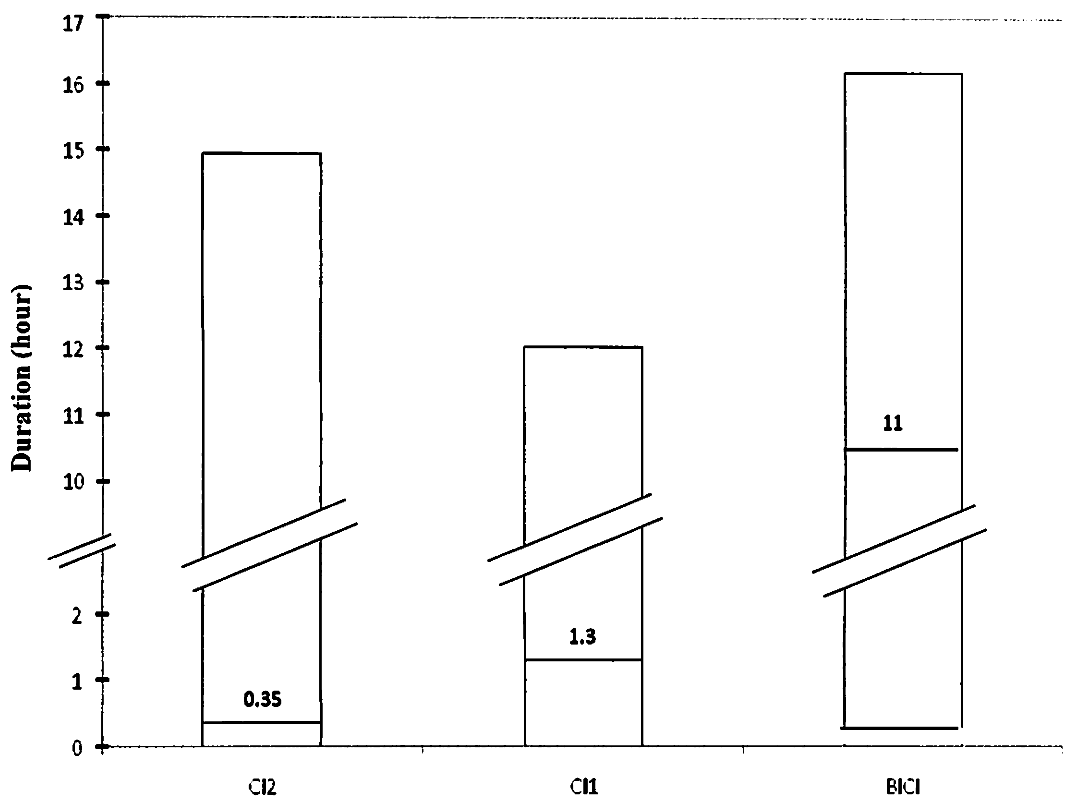

Fig. 3. Bar graph of hours used for 21 participants with CI2 alone, CI1 alone, and BICI. Each bar represents the range of minimum and maximum hours used (at the ends of boxes), and mean values are indicated in the bars.

Pattern of Usage over 24 Months

Figure 4 shows the changes of average time spent CI2 alone, CI1 alone and BICI per day over 24 months post switch-on of the second implant. Generally, the pattern of use for sequentially implanted children and adolescents remained the same as the mean usage with CI2 or CI1 alone and BICI. The participants used both implants together most of the time and used CI1 more than CI2 alone. A decline in usage of both implants in any particular month was always associated with an increase in usage of either CI1 or CI2 alone.

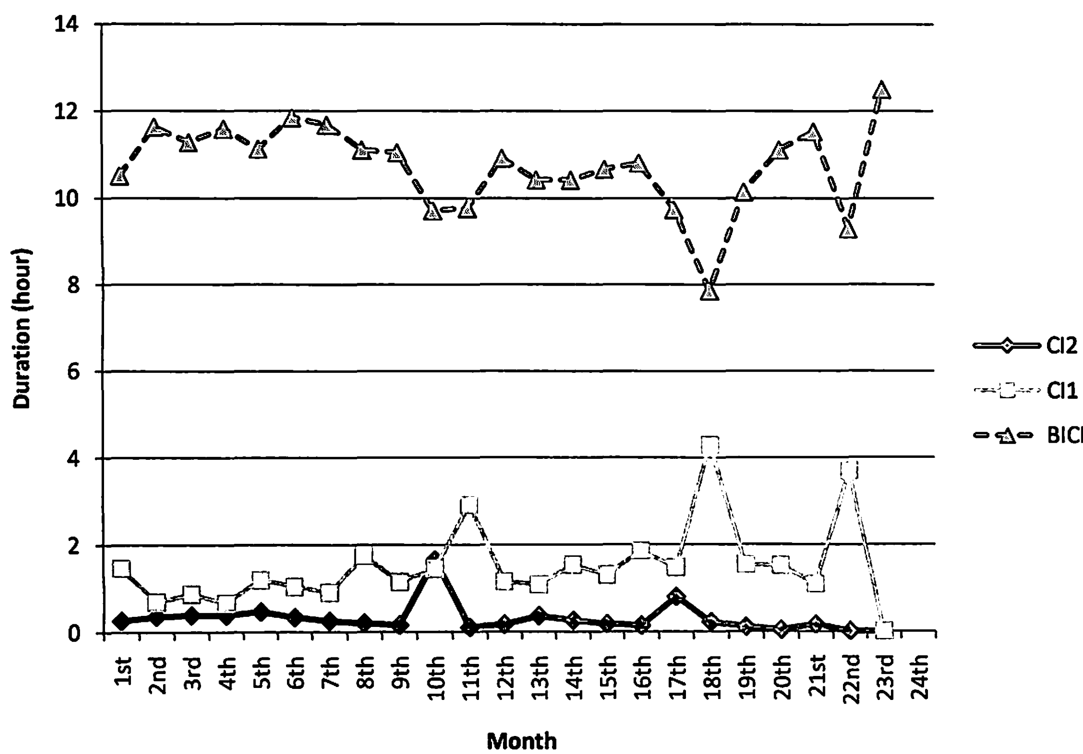

Fig. 4. Mean usage (in hours) of each device per day for 21 subjects over 24 months post switch-on of the second implant.

Figure 5 shows that data from subject 11 (S11) at month 22 (point E), S13 at month 10 (point A), S14 at month 11 (point C) and 18 (point D), and S16 at month 17 (point B) were outliers and resulted in peaks and troughs in figure 4. All identified outliers are more than 2 standard deviations than the mean. Subjects had changed their routine of device use for various reasons.

Subject 13 (month 10) and S16 (month 17) had to use their CI2 only when their speech processor for CI1 was sent for repair. Likewise, S14 had to use CI1 alone when their CI2 speech processor was sent for repair at month 11, and also when they lost their CI2 speech processor at month 18. S11 was unable to complete the recording at month 22. Due to the fact that these subjects showed atypical use at these times for the above reasons, these data points for these subjects were excluded from further analysis from this point onwards.

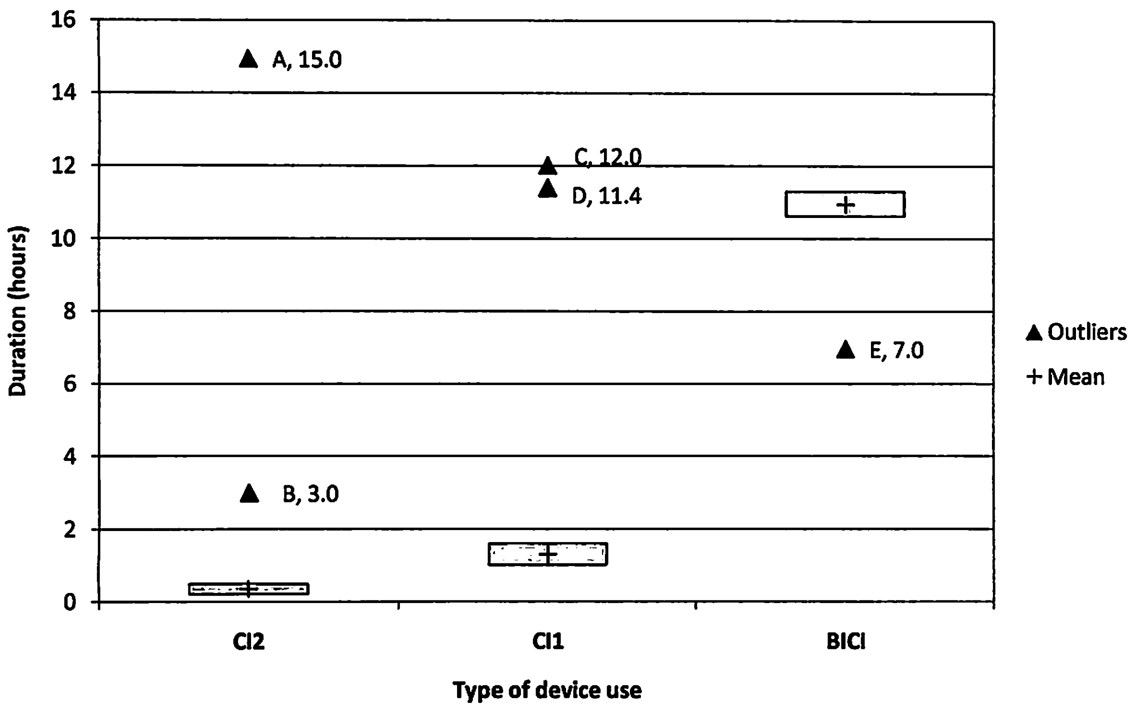

Fig.5. Each bar represents the 95% confidence interval (N=21). Each data point represents the data point 2 SD from the mean.

After removing the outliers at the time points listed above, the maximum number of hours of CI2 alone use per day use decreased from 15 to 2.4 hours, while CI1 alone use was reduced from 12 to 9.5 hours per day (see figure 6).

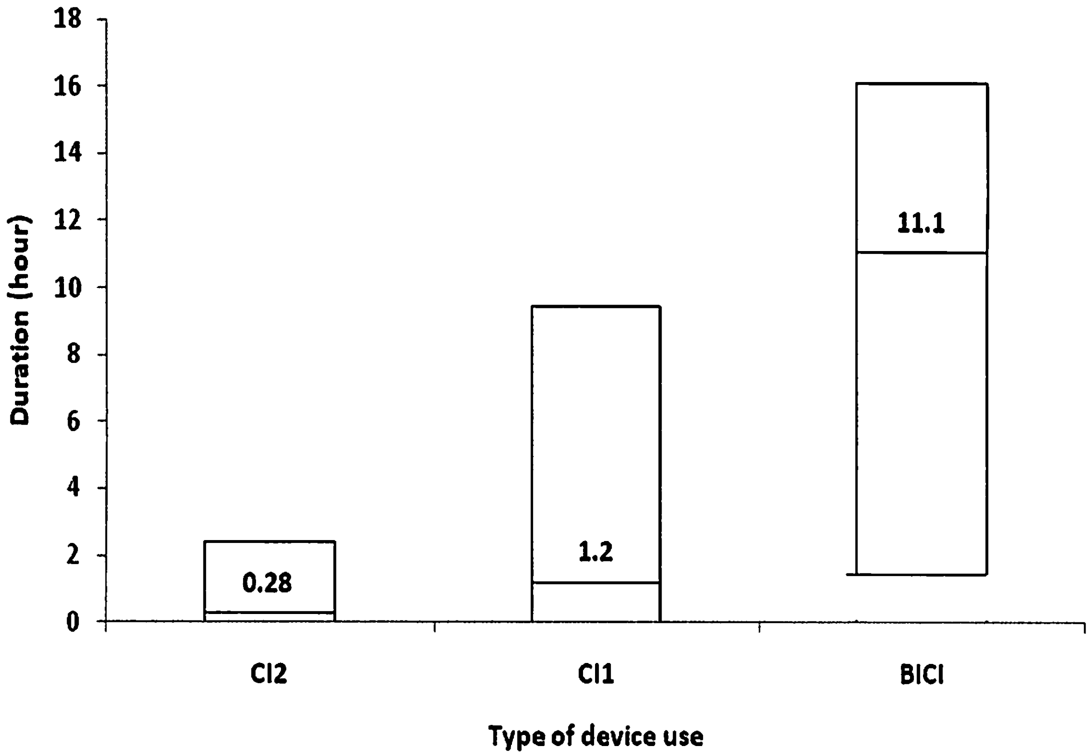

Fig. 6. Bar graph of hours used for 21 subjects with CI2 alone, CI1 alone, and BICI, excluding the outliers. Each bar graph represents the range of minimum and maximum hours of use (ends of boxes), and the mean value is indicated in each bar.

CI2 alone

Figure 7 shows individual monthly average CI2 alone usage patterns for 21 subjects over the 24-month period following CI2 switch-on. CI2 alone usage in children and adolescents ranged from 0 to 0.5 hour per day over 24 months post switch-on of CI2. This figure also shows that usage of CI2 alone gradually decreased over a 24 month period. Generally, all of the subjects used CI2 alone for less than half an hour per day.

In the first 12 months after receiving the second implant, there was a consistent pattern of increasing usage in the first 5 months, followed by a gradual decrease through to the 9th month. At the 12 month post-CI2 implantation point, CI2 alone usage had gradually dropped to zero hours per day.

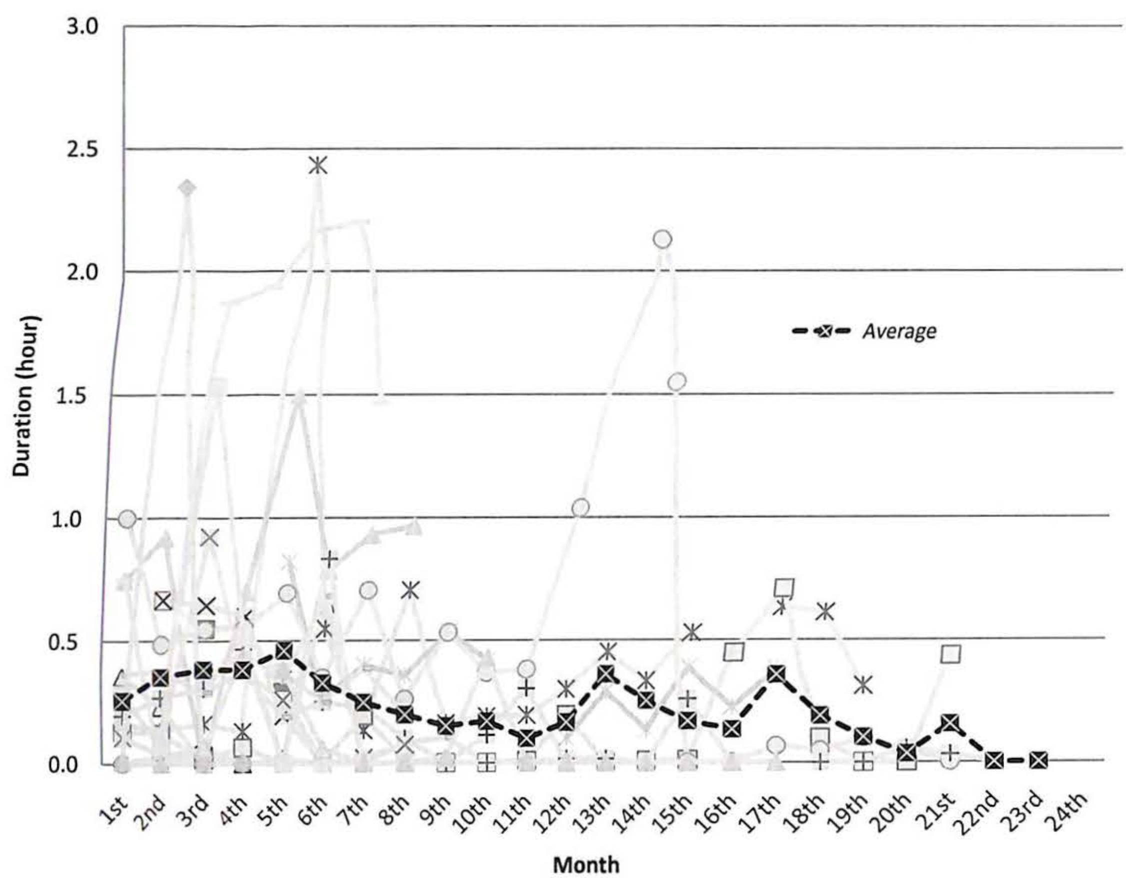

Fig. 7. CI2 only usage by all participants (in grey) and mean CI2 only usage in hours per day (thick, dotted line) over 24 months post-switch on of CI2.

CI1 alone

Figure 8 shows CI1 alone usage for all participants. The monthly average CI1 alone usage ranged from 0 to 2.51 hours per day, which is a wider range than for CI2 usage. The CI1alone usage had gradually dropped to zero hours per day after 18 months post switch-on of CI2.

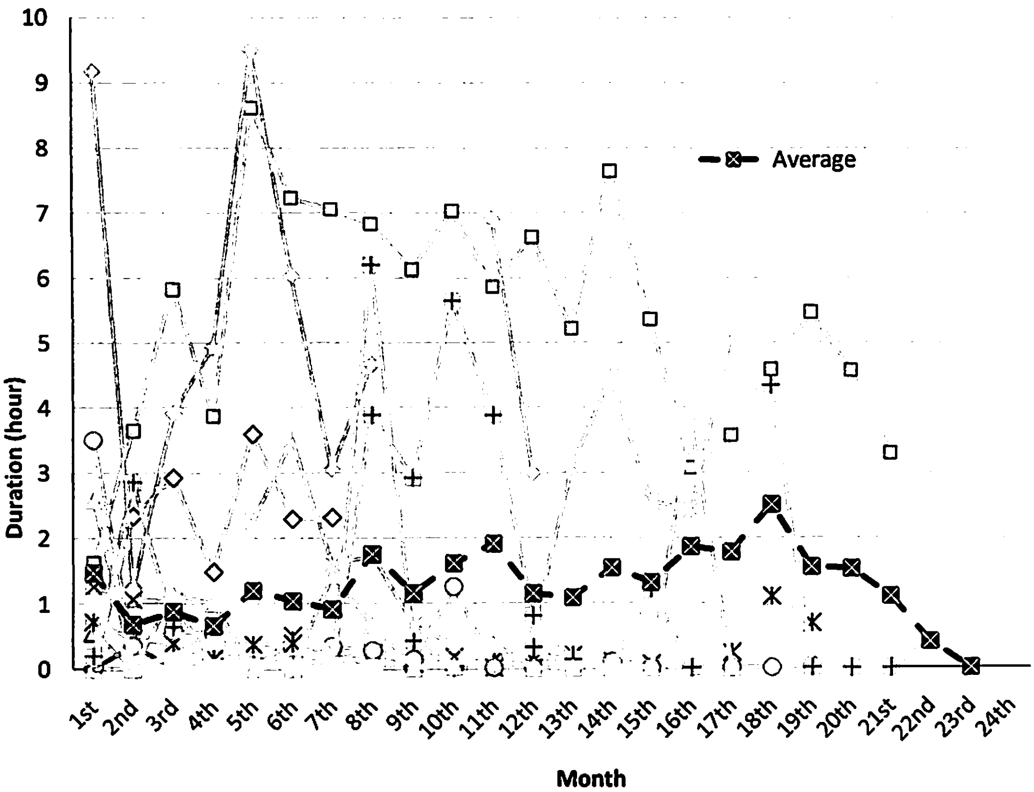

Fig. 8. CI1 only usage for all participants (in grey) and mean of CI1 only usage in hours per day (thick, dotted line) over 24 months post-switch on of CI2.

Both together (BICI)

Figure 8 shows both individual and monthly average BICI usage over the 24-month period surveyed. The average BICI usage ranged from 9.3 to 12.5 hours per day. In the first 12 months, the hours of BICI usage were fairly consistent; from 10.5 to 11.9 hours per day as shown in Figure 8. Despite falls in usage in the latter 12 months for some subjects, the average usage for the group gradually increased to 12.5 hours per day by month 24.

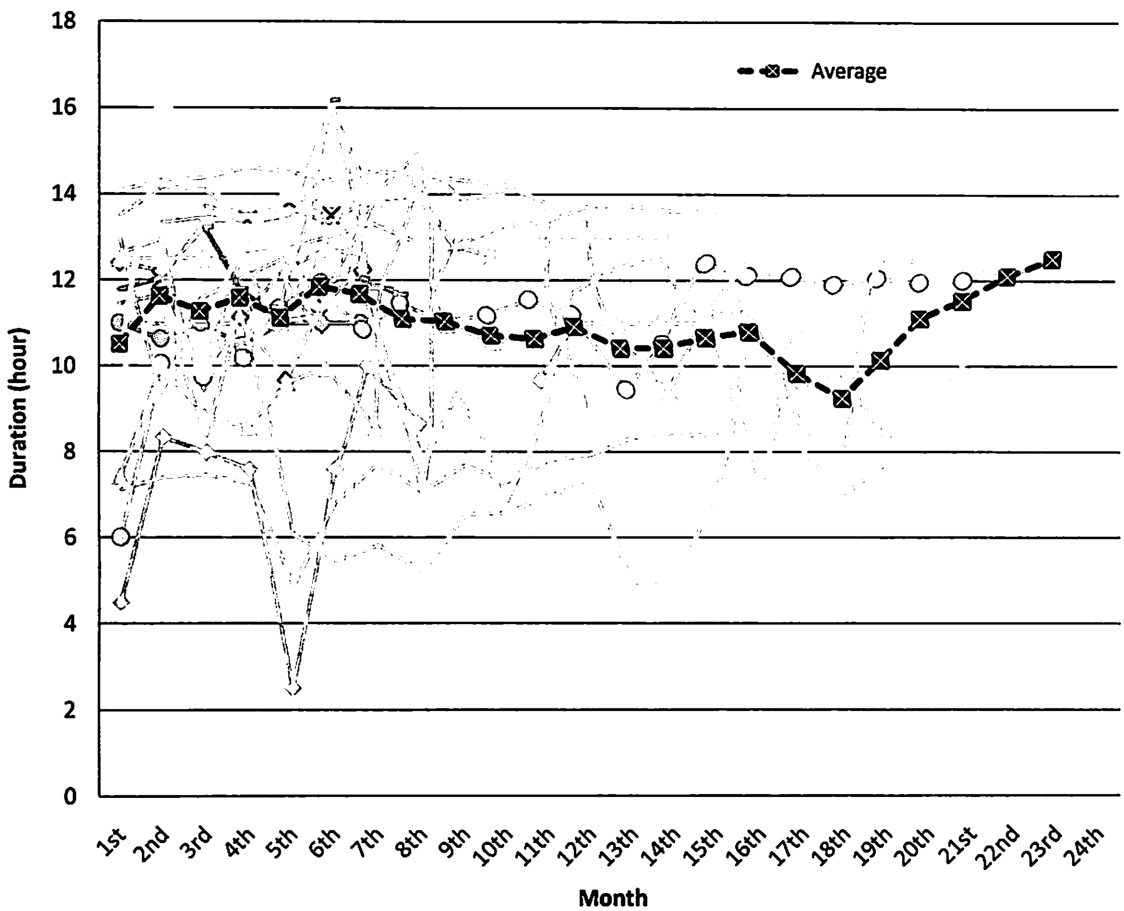

Fig. 9. Individual duration of BICI usage for all 21 participants (in grey) and mean BICI usage in hours per day (black, dotted line) over 24 months post-switch on of CI2.

Comparison between sequential and simultaneous implantation

Figure 10 shows the pattern of device use by three children with simultaneous bilateral implants over a period of 24 months. As is shown, the CI1 only and CI2 alone usage is nearly 0 hours, particularly after month 13. Conversely, it can be seen that the time spent wearing both implants together increased steadily over the 24-month period.

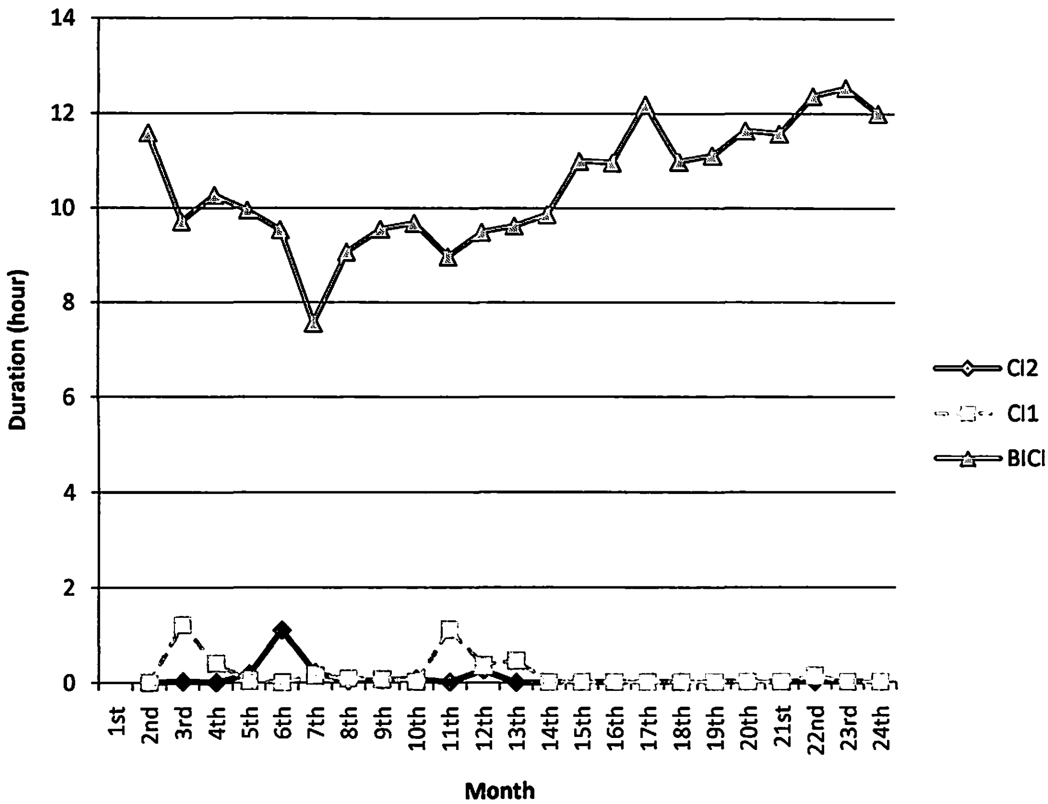

Fig. 10. Mean usage time (in hours) for each device per day over 24 months post switch-on of both CIs for three children with simultaneous bilateral implants (N=3). CI2 alone use is represented by diamonds, CI1 alone use is represented by squares, and BICI use is represented by triangles.