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Author/s:

Galvin, KL;Mok, M

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Everyday listening performance of children before and after receiving a second cochlear implant:

Results using the parent version of the Speech, Spatial and Qualities of Hearing Scale

Karyn L. Galvin<sup>1</sup> and Mansze Mok<sup>1</sup>

<sup>1</sup> Department of Audiology and Speech Pathology, The University of Melbourne

email: kgalvin@unimelb.edu.au

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#### Abstract

**Objectives:** To evaluate change in individual children's performance in general areas of everyday listening following sequential bilateral implantation, and to identify the specific types of listening scenarios in which performance change occurred. The first hypothesis was that parent performance ratings for their child would be higher in the bilateral versus unilateral implant condition for each section of the Speech, Spatial and Qualities of Hearing Scale for Parents, viz: speech perception, spatial hearing, and qualities of hearing. The second hypothesis was that the rating for the participant group would be higher in the bilateral condition for speech perception items involving group conversation or background noise, spatial hearing items, and qualities of hearing items focused on sound segregation or listening effort.

**Design:** Children receiving sequential bilateral implants at the Royal Victorian Eye and Ear Hospital and fulfilling selection criteria (primarily no significant cognitive or developmental delays, and oral English language skills of child and parent sufficient for completing assessments) were invited to participate in a wider project evaluating outcomes. The assessment protocol for older children included the Speech, Spatial and Qualities of Hearing Scale for Parents. All children (n=20; aged 4 to 15 years) whose parents completed the Scale preoperatively and at 24-months postoperatively were included in this study. Ratings obtained preoperatively in the unilateral implant condition (or unilateral implant plus hearing-aid for 4 participants) were compared to those obtained postoperatively in the bilateral implant condition.

**Results:** Bilateral ratings were significantly higher than unilateral ratings on the speech section for 12 children ( $W \geq 7.0$ ;  $p \leq 0.03$ ), on the spatial section for 13 children ( $W \geq 15.0$ ;  $p \leq 0.03$ ), and on the qualities of hearing section for nine children ( $W \geq 15.0$ ;  $p \leq 0.047$ ). The difference between conditions was unrelated to time between implants or age at bilateral implantation ( $r \leq 0.4$ ,  $p \geq 0.082$ ). The median bilateral ratings for the participant group were higher for all eight speech perception items, including, as predicted, those involving group conversation and/or background noise ( $W \geq 37.5$ ;  $p \leq 0.043$ ). Also, as predicted, the median bilateral ratings for the participant group were higher for all six spatial hearing items ( $W \geq 88.0$ ;  $p \leq 0.014$ ), and for qualities of hearing items related to sound segregation ( $W \geq 94.0$ ;  $p \leq 0.029$ ), but not for those related to listening effort ( $W \leq 92.0$ ;  $p \geq 0.112$ ).

**Conclusions:** Seventy-five percent of parents perceived change in their child's daily listening performance postoperatively, and 25% perceived change across all three listening areas. For the overall participant group, the parents perceived a change in performance in the majority of specific listening scenarios, although change was limited in the qualities of hearing section, including no change in listening effort. Previous research suggests postoperative change was likely due to the headshadow effect and improved spatial hearing. Additional contributions may have been made by binaural summation, redundancy, and unmasking. For these participants, differences between device conditions may have been limited by their relatively old age at implantation, delay between implants, and limited bilateral experience. These results will provide valuable information to families during preoperative counselling and postoperative discussions about expected progress and evident benefit.

## Introduction

In many countries an increasing proportion of children with severe-profound hearing loss are receiving bilateral cochlear implants (CIs). There is objective evidence in the literature that performance with bilateral CIs is typically superior to that with a unilateral CI on tests of spatial hearing (Galvin et al., 2011; Grieco-Calub & Litovsky, 2010; Lovett et al., 2010) and of speech perception, particularly in noise (Galvin et al., 2007; Lovett et al., 2010; Sparreboom et al., 2010; van Deun et al., 2010). There is also objective evidence that listening effort for a dual-task paradigm is reduced for some individuals when using bilateral CIs (Hughes & Galvin, 2013). This type of objective evidence is important for clinics formulating selection criteria, for families considering bilateral implantation, and for government and health bodies making policy and funding decisions regarding bilateral implantation. Subjective data are also of significant value. The importance of parent-reported information in assessing the outcomes of implantation has been emphasised by many researchers, including Archbold et al. (2008), Chundu et al. (2013), Huttunen et al. (2009), and Sparreboom et al. (2012a). Parents are in the best position to provide information on their child's performance with their implant(s) in everyday listening scenarios. This type of information is of particular interest to families and older children who wish to know the real-life situations in which bilateral implants may provide additional advantages.

The Speech, Spatial, and Qualities of Hearing Scale (SSQ), is a self-report questionnaire for adults which was designed to obtain information about real-life listening performance (available at <http://www.ihr.mrc.ac.uk/products/display/ssq>; Gatehouse & Noble, 2004; Noble & Gatehouse, 2004). Real-life environments are often dynamic, involving as they do multiple sound sources which overlap in space and time. Effective functioning therefore requires the listener to identify and focus on the sound source or sources of interest, and to switch attention between them. At the same time, the listener also needs to monitor the auditory environment for new sound sources of potential interest. Performance of these tasks relies heavily on binaural hearing. The SSQ focusses mainly on hearing functions for which the binaural system is essential, and is therefore an appropriate tool for comparing the performance of listeners using unilateral versus bilateral hearing devices. Each item in the SSQ consists of a description of an everyday listening scenario, and a 0 to 10 scale on which the respondent indicates a performance rating for that scenario. The three sections of the scale cover speech perception, spatial hearing,

and qualities of hearing. In order to provide a questionnaire suitable for use in assessing the performance of children using a unilateral versus bilateral CIs, the SSQ was adapted to produce the SSQ for Parents (SSQ-P) (refer to Galvin and Noble (2013) for details of the adaptation and to Supplemental Digital Content) (see Text, Supplemental Digital Content 1, listening scenarios in the SSQ-P). As noted above, many researchers have emphasised the value of parent reported data. Parents observe listening performance from the point of view of a key communication partner. Furthermore, with their experience of listening with normal hearing, parents could be expected to have a greater appreciation of their child's relative level of performance. Anecdotal feedback from older children using CIs has indicated that children with early-onset of hearing loss lack an understanding of the auditory capabilities of listeners with normal hearing; thus they may over-rate their own ability to, for example, locate sound sources. The additional advantage of parent-reported data is that younger children, who cannot provide self-reports, can also be included in the participant group. The disadvantage of the parent-report is that the ratings are based on observation rather than direct experience, and parents cannot answer questions regarding, for example, the naturalness and clarity of sound. As an alternative (which was not utilised in the present study), the original SSQ was also adapted to produce the self-report SSQ for Children (Galvin & Noble, 2013).

The SSQ-P has been administered previously in studies making between-participant (Beijen et al., 2007; Lovett et al., 2010; Sparreboom et al., 2012a) and within- participant (Galvin et al., 2010; Galvin et al., 2007; Kim et al., 2013; Sparreboom et al., 2012a) comparisons of performance with unilateral versus bilateral CIs. Analysis of results focussed on group performance for each broad area covered by a section of the SSQ-P, and did not analyse the performance of individuals nor results for specific listening scenarios in which benefit was evident. The between-participant comparisons indicated that ratings were significantly higher for the bilateral implant group for the spatial section in all three studies (Beijen et al., 2007; Lovett et al., 2010; Sparreboom et al., 2012a) and for the speech section in one study (Lovett et al., 2010). In the studies of Sparreboom et al. (2012a) and Beijen et al. (2007), the small size of the unilateral group ( $n = 5$  and  $9$  respectively) may have limited the power to detect differences between device groups on the other SSQ sections. In addition, in the latter study, the unilateral group was significantly older at testing (mean  $5.4$  years versus  $3.6$  years for the bilateral group), and may have had an age advantage for speech perception performance, particularly in group

conversations. The within-participant comparisons indicated that group ratings were significantly higher in the bilateral condition for all three SSQ-P sections, viz: speech, spatial, and qualities of hearing. This difference between conditions was evident for a group of 30 children which had a median inter-implant delay of 3.3 years, a median age of 5 years at bilateral implantation, and 2 years of experience (Sparreboom et al., 2012a), and also for a group of 42 children with a longer inter-implant delay (mean 5.5 years), a slightly older age at bilateral implantation (mean 9.7 years), and less experience (6 months) (Kim et al., 2013). The finding of higher ratings across all three sections in these previous studies was consistent with the data reported by Galvin et al. (2007) and Galvin et al. (2010). These authors reported higher bilateral condition ratings across the three sections for most participants, although statistical analysis was not conducted for the small groups ( $n = 8$  to  $10$ ) involved. Clearly, the disadvantage of the within-participant comparison is that the participants are older and have more hearing experience when performance in the bilateral condition is rated. Given this potentially confounding effect, Sparreboom et al. (2012a) obtained SSQ-P ratings for a group of unilaterally implanted children, and then compared them with ratings obtained for the same children 12 months later. There was no significant difference in any of the ratings, suggesting that, for this group aged approximately 4.5 to 9.5 years, parental ratings of performance did not change with increased age or hearing experience.

It is always of significant clinical value to evaluate relationships between the outcomes of implantation and other factors, including demographic characteristics. Of the studies in the literature reporting results on the SSQ-P, only Sparreboom et al. (2012a) examined the relationships between parent ratings and other factors. These authors found that, while parent ratings were not related to the age at first or second implantation, nor to speech perception in noise performance, higher parent ratings were related to superior performance on a test of spatial hearing and a longer duration of bilateral CI experience.

In summary, these studies provided consistent evidence that parents' ratings of overall spatial hearing performance were higher for groups of children using bilateral CIs; less consistent, yet still strong, evidence that ratings of overall speech perception performance were higher; and some evidence that ratings of overall performance relating to qualities of hearing were higher for some groups. Although this is a useful picture of parent-perceived group improvement in general

areas of everyday listening with bilateral CIs, additional investigation is warranted in order to determine the proportion of individual children for whom parents perceive such improvements and to identify the specific listening scenarios in which improvement occurs. Such information will be of significant interest to families and older children considering bilateral implantation.

The aim of this study was to evaluate change in the performance of individual children in general areas of everyday listening following sequential bilateral implantation, and to identify the specific types of listening scenarios in which performance change occurred. The first hypothesis was that, for individual children, parent ratings of performance on each of the speech perception, spatial hearing, and qualities of hearing sections of the SSQ-P would be significantly higher in the bilateral compared with the unilateral CI condition. The second hypothesis was that group ratings of performance would be significantly higher in the bilateral compared with the unilateral CI condition for the following items on the SSQ-P: speech perception items involving group conversation or background noise (items A1, A3, A4, A5, A6, and A8), all spatial hearing items, and qualities of hearing items focused on the segregation of sounds or on listening effort (items C1, C2, C7, and C8).

## Materials and Method

Ethical approval for this work was given by the Human Research Ethics Committee of the Royal Victorian Eye and Ear Hospital, Melbourne (Project No. 02/506H/07).

### *Participants*

Children and young adults who received bilateral CIs at the Royal Victorian Eye and Ear Hospital Cochlear Implant Clinic in Melbourne and met the selection criteria were invited to participate in a broader bilateral CI research project. The selection criteria were: onset of hearing loss prior to adolescence, no significant developmental or cognitive delays reported by professionals working with the child, sufficient oral language skills to participate in testing, a parent with sufficient English language skills to provide feedback on the child's progress, and a record of generally attending scheduled clinic appointments. The assessment protocol for children 4 years and over included administration of the SSQ-P. Of the parents who were available to complete the SSQ-P preoperatively ( $n = 28$ ), twenty also completed the SSQ-P at 24 months postoperatively and are therefore included in the present study.

The participants were the mothers, and one grandmother in the primary carer role, of 20 children who received sequential bilateral CIs between 4 and 15 years of age. For convenience, the term “parents” is used throughout the manuscript. Details of the children’s hearing loss and implantation are provided in Table 1. In the second implanted ear, the three-frequency pure-tone average (500 Hz, 1 kHz and 2 kHz) was greater than 90dBHL for all children and greater than 100dBHL for 18 children. Only four parents reported that their child (Ch11, 13, 18 and 19) used a contralateral hearing aid full time, allowing them to rate their child’s performance in the CI plus hearing aid condition.

### *Materials*

As noted in the introduction, the SSQ-P is an adaptation of the original adult version of the SSQ (Galvin & Noble, 2013). Section A (Speech Perception) included nine items, although data for only eight are included here. Item 9 described conversation on the telephone; this item was not relevant to the comparison of unilateral versus bilateral CIs as many children did not use the telephone, or used a direct input cable. Section B (Spatial Hearing) included six items and Section C (Other Qualities) included eight items.

Table 1: Demographic information relating to etiology, age at onset, age at implant, and implant type for the 20 children.

<i>Etiology</i>	Unknown: n = 8	Genetic Connexin 26: n = 3 Other: n = 2	Syndrome WVA <sup>1</sup> : n = 2 KID <sup>2</sup> : n = 2 Waardenburg's: n=1	Meningitis: n = 2
<i>Age at onset</i>	Congenital n = 10	Assumed congenital n = 8	Acquired (onset <22mo) n = 2	
<i>Age at implant</i>	CI1	CI2	Time between	
mean (yrs) [SD]	2.1 [1.0]	7.9 [2.9]	5.8 [2.4]	
range	0.9 – 4.6	4.0 – 14.4	2.4 – 10.2	
<i>Nucleus<sup>3</sup> implant type: CI-2/CI-1</i>	Freedom <sup>4</sup> /Freedom n = 2	Freedom/CI24 <sup>4</sup> n = 10	CI24/CI24 n = 4	CI24/CI22 <sup>5</sup> n = 4

<sup>1</sup> Wide Vestibular Aqueduct syndrome. <sup>2</sup> Keratitis-Ichthyosis-Deafness syndrome. <sup>3</sup> Nucleus implants manufactured by Cochlear Limited, Macquarie University, Australia. <sup>4</sup> Implant with 22 electrodes and 2 extra-cochlear electrodes. <sup>5</sup> Implant with 22 electrodes.

*Procedure*

The SSQ-P was administered to the parent prior to the child's second (bilateral) CI operation to obtain ratings of performance in the unilateral CI condition or the unilateral CI plus contralateral hearing aid condition (UniCI(+HA)). The SSQ-P was readministered to the same parent at 24-months post-bilateral implantation to obtain performance ratings in the bilateral CIs condition (BiCIs). During this second administration, the parent was not able to refer to the ratings they had previously provided for the UniCI(+HA) condition.

At each assessment point, each of the three sections of the SSQ-P was administered in a separate interview. At least one week prior to each interview, the parent was provided with the list of listening scenarios for the relevant section. This "observation period" of at least one week provided the parent with the opportunity to observe the child in the types of listening scenarios described in the relevant section of the scale prior to being required to rate the child's performance. Given a minimum observation period of one week for each section, at least three weeks were required for administration of the complete SSQ-P. During each of the three interviews, the parent viewed a copy of the relevant section of the SSQ-P. For each scenario, the interviewer ensured the parent's correct interpretation of the scenario and then requested a rating of the child's performance in that type of scenario using a visual-analogue scale from zero to ten. Three alternative response options were also offered: "Do not know", "Would not hear it", and "Not applicable".

The aim was for an observation period of one to two weeks. The actual length of observation periods depended on the availability of the parent. For the collection of the UniCI(+HA) condition data, the majority of observation periods ( $n = 51$  out of 60) were between one and four weeks (mean 11.7 days). Three observation periods were less than one week. In six instances (all sections for Ch10 and 11), the mother was unavailable to participate in the observation periods, so that ratings were collected without observation periods. The majority of the 60 interviews were conducted by phone ( $n = 48$ ) or face-to-face ( $n = 11$ ), while the mother of Ch3 completed Section B independently prior to being contacted for interview.

The majority of the BiCIs condition data was collected at approximately 24-months post-bilateral implantation; due to the limited availability of the family, data for Ch20 was collected at 18 months and data for Ch15 at 29 months. The majority of observation periods ( $n = 51$ ) were

between one and four weeks. In five instances the observation period was 30 days or more, and in four instances (Section B for Ch1, and Section C for Ch1, 3 and 14), there was no observation period. The majority of the 60 interviews were conducted by phone ( $n = 48$ ) or face-to-face ( $n = 7$ ), and two were by email. For Ch4, the mother completed all three sections independently as she was not available for interview.

## Results

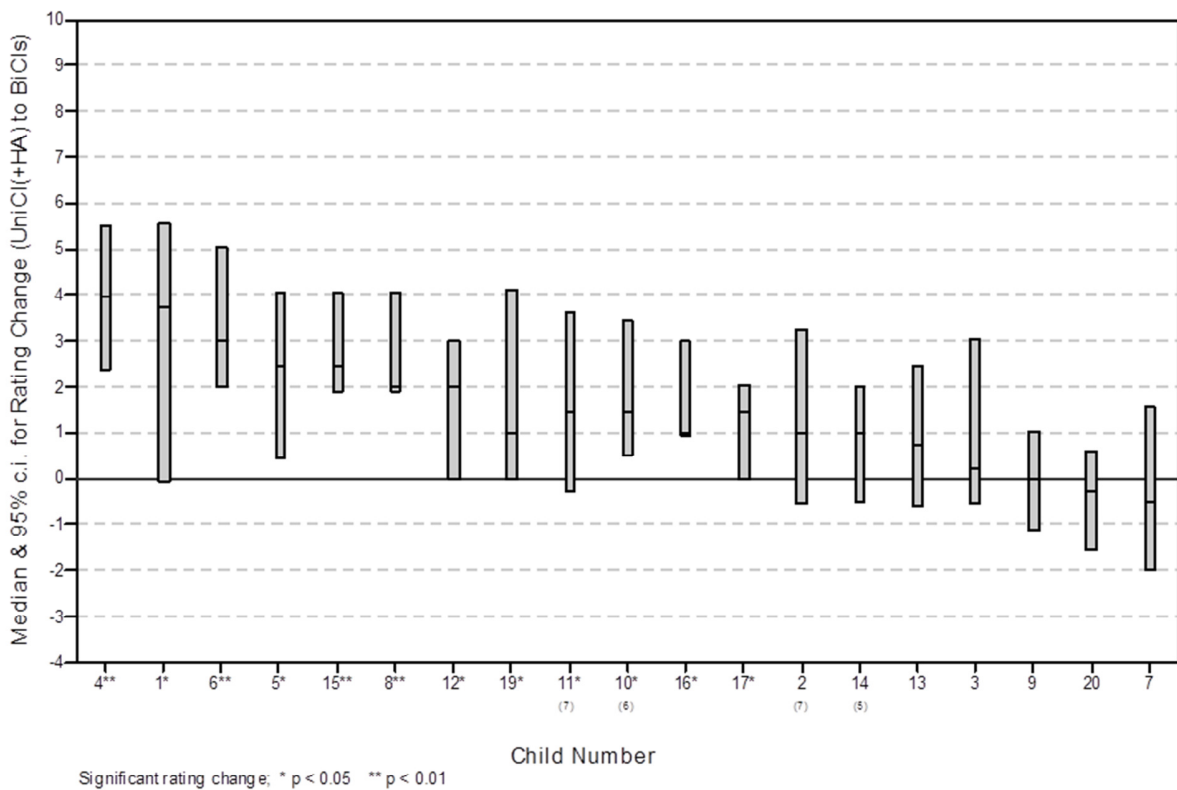


Figure 1: Median (horizontal bar) and 95% confidence interval (c.i.) (lower and upper box boundary) for the change in parent rating between the UniCI(+HA) and BiCIs conditions for all items ( $n = 8$ ) of Section A (Speech Perception) of the SSQ-P for each child. Reduced sample sizes for individual children (due to incomplete data) are indicated in brackets.

The median differences in the parent ratings between the UniCI(+HA) and the BiCIs condition for each child on Section A, B, and C are presented in Figures 1, 2 and 3 respectively. One-tailed Wilcoxon Signed Ranks tests were used to compare across device conditions. For Section A

(Speech Perception), BiCIs condition ratings were significantly higher than UniCI for the group ( $W = 7200.5$ ;  $p < 0.001$ ) and for 12 individual children ( $W \geq 7.0$ ;  $p \leq 0.03$ ), but not for the remaining seven children ( $W \leq 9.0$ ;  $p \geq 0.086$ ). Ratings for Ch18 were not included as the parent provided a rating in both conditions for only one item.

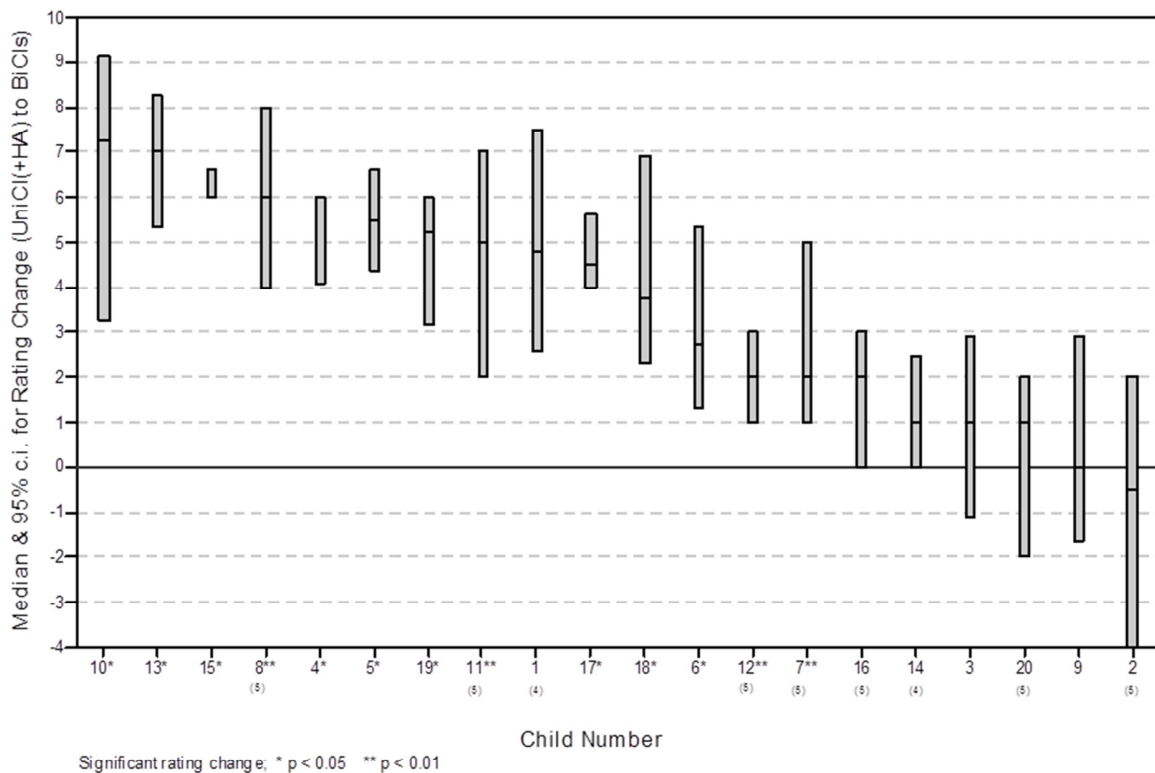


Figure 2: Median (horizontal bar) and 95% confidence interval (c.i.) (lower and upper box boundary) for the change in parent rating between the UniCI(+HA) and BiCIs conditions for all items ( $n = 6$ ) of Section B (Spatial Hearing) of the SSQ-P for each child. Reduced sample sizes for individual children (due to incomplete data) are indicated in brackets.

For Section B (Spatial Hearing), BiCIs condition ratings were significantly higher for the group ( $W = 5385.5$ ;  $p < 0.001$ ) and for 13 children ( $W \geq 15.0$ ;  $p \leq 0.03$ ), but not for seven children ( $W \leq 16.0$ ;  $p \geq 0.05$ ). For Section C (Other Qualities), BiCIs condition ratings were significantly higher for the group ( $W = 5818.5$ ;  $p < 0.001$ ) and for nine children ( $W \geq 15.0$ ;  $p \leq 0.047$ ), but not for 11 children ( $W \leq 18.5$ ;  $p \geq 0.10$ ). BiCIs condition ratings were significantly higher across all three SSQ-P sections for five children (Ch4, 5, 8, 11 and 15) and across two sections for eight

children (Sections A and B for Ch6, 10, 12, 17 and 19; Sections A and C for Ch1 and 16; and Sections B and C for Ch18). In contrast, ratings were not higher in any section for four children (Ch3, 9, 14, 20).

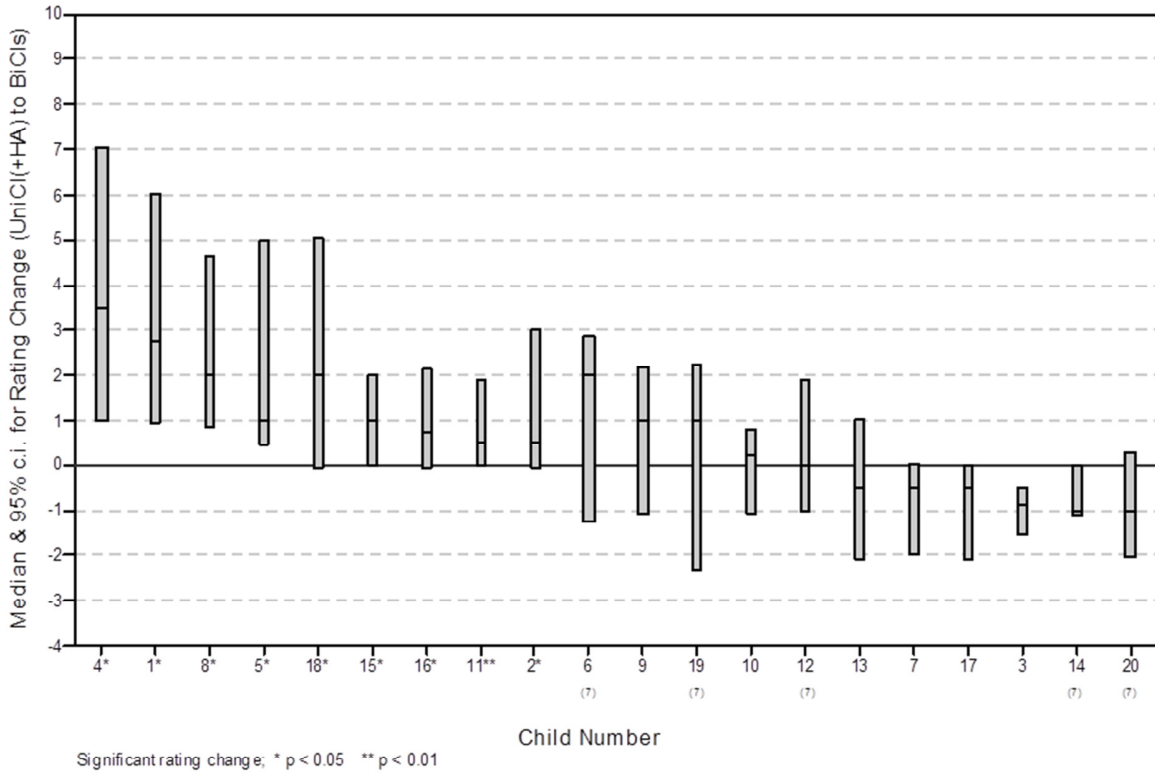


Figure 3: Median (horizontal bar) and 95% confidence interval (c.i.) (lower and upper box boundary) for the change in parent rating between the UniCI(+HA) and BiCIs conditions for all items (n = 8) of Section C (Other Qualities of Hearing) of the SSQ-P for each child. Reduced sample sizes for individual children (due to incomplete data) are indicated in brackets.

In general, Pearson correlation coefficients calculated for each section of the SSQ-P indicated no relationship between the demographic factors of age at first CI, time between CIs or age at bilateral implantation and the mean parent rating in the BiCIs condition ( $r \leq 0.23$ ,  $p \geq 0.325$ ) or the mean difference in parent rating (UniCI(+HA) versus BiCIs) ( $r \leq 0.40$ ,  $p \geq 0.082$ ) for individual children. The exception to this occurred for results on Section C (Qualities of Hearing), with a significant relationship identified between the mean difference in parent rating and age at first CI ( $r = 0.51$ ,  $p = 0.021$ ).

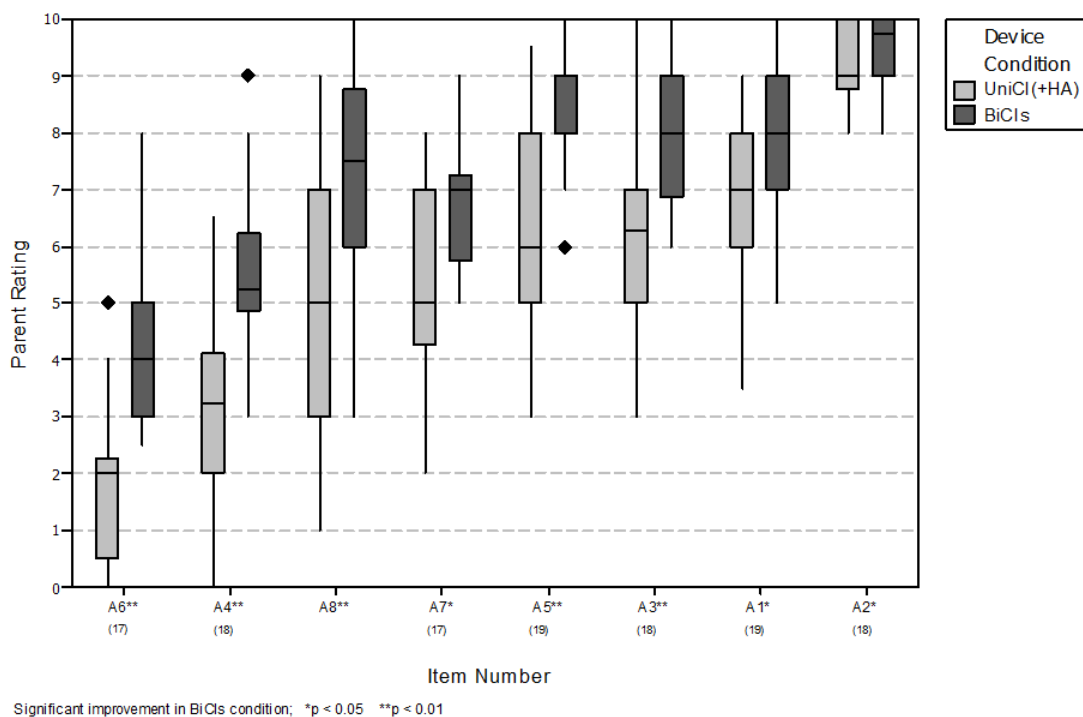


Figure 4: Median (horizontal bar), 25<sup>th</sup> and 75<sup>th</sup> percentiles (lower and upper box boundary), and minimum and maximum (whiskers) parent ratings for the group ( $n = 20$ ) on each item of Section A (Speech Perception) of the SSQ-P in the UniCI(+HA) and BiCIs conditions. Reduced sample sizes for individual items (due to incomplete data) are indicated in brackets. Black diamonds represent outliers.

Boxplots of the parent ratings for the group in the UniCI(+HA) and the BiCIs conditions for each item in each of Section A, B, and C are presented in Figures 4, 5, and 6 respectively. A reduced sample size is indicated when a child was excluded from the analysis because the parent ratings were not provided in both conditions. The median ratings for the eight items in Section A (Speech Perception) were significantly higher, by 0.75 to 2.5 points, in the BiCIs condition ( $W \geq$

37.5;  $p \leq 0.043$ ). The median ratings for the six items in Section B (Spatial Hearing) were significantly higher, by 2.5 to 6 points, in the BiCIs condition ( $W \geq 88.0$ ;  $p \leq 0.014$ ). The difference in median ratings for the eight items in Section C (Other Qualities) ranged from zero to 1.25 points higher in the BiCIs condition, with the difference significant for items 1, 2, and 4 ( $W \geq 77.5$ ;  $p \leq 0.029$ ), but not for the remaining five items ( $W \leq 122.0$ ;  $p \geq 0.058$ ).

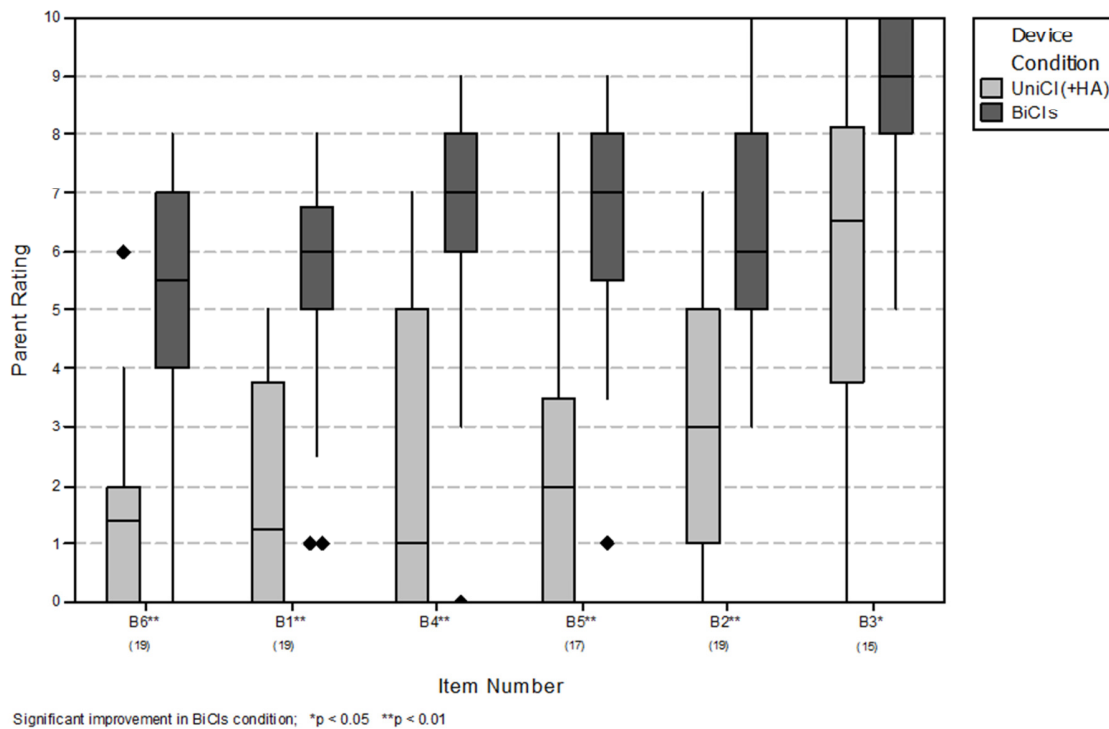


Figure 5: Median (horizontal bar), 25<sup>th</sup> and 75<sup>th</sup> percentiles (lower and upper box boundary), and minimum and maximum (whiskers) parent ratings for the group ( $n = 20$ ) on each item of Section B (Spatial Hearing) of the SSQ-P in the UniCI(+HA) and BiCIs conditions. Reduced sample sizes for individual items (due to incomplete data) are indicated in brackets. Black diamonds represent outliers.

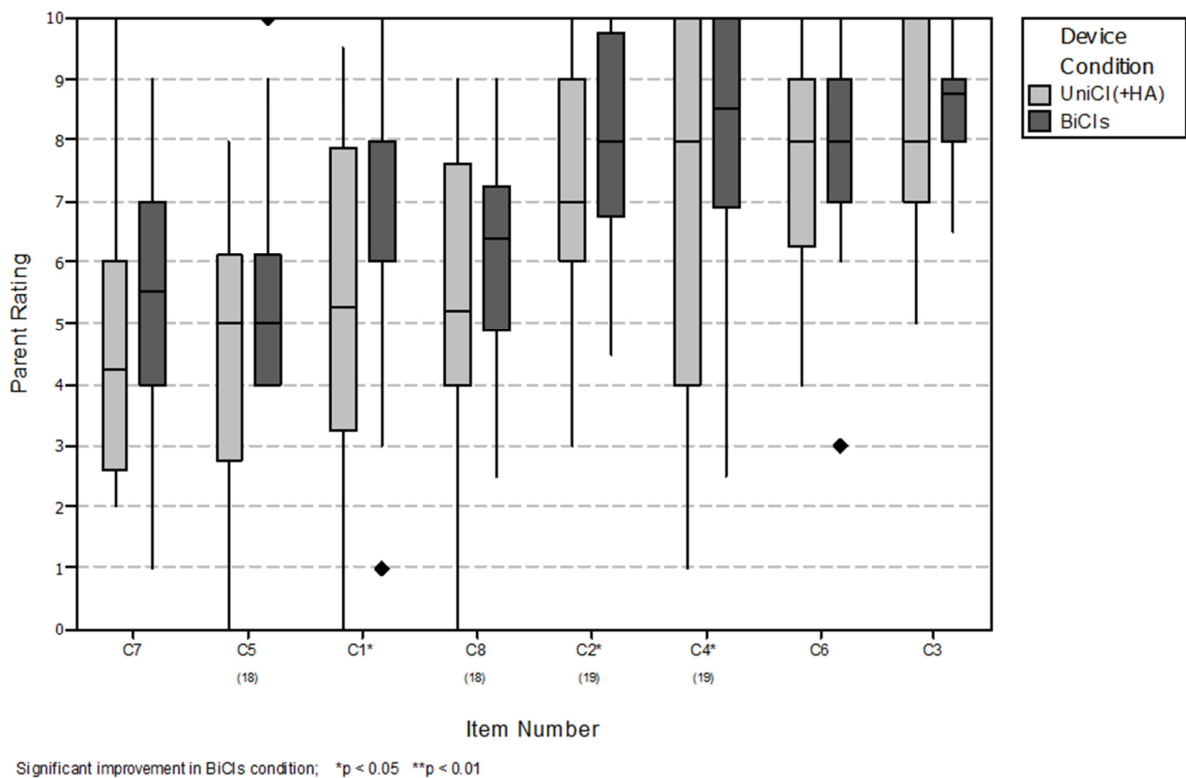


Figure 6: Median (horizontal bar), 25<sup>th</sup> and 75<sup>th</sup> percentiles (lower and upper box boundary), and minimum and maximum (whiskers) parent ratings for the group (n = 20) on each item of Section C (Other Qualities of Hearing) of the SSQ-P in the UniCI(+HA) and BiCIs conditions. Reduced sample sizes for individual items (due to incomplete data) are indicated in brackets. Black diamonds represent outliers.

## Discussion

The results provided partial support for hypothesis one, i.e., that parent ratings of performance would be significantly higher in the BiCIs condition for individual children for the speech perception, spatial hearing, and qualities of hearing sections of the SSQ-P. Ratings were higher for 63%, 65%, and 45% of children for each section respectively. Ratings were higher across all three sections for 25% of children, on two or more sections for 65%, and on no sections for 25%. The variation in results across individuals is consistent with the variation in objectively measured bilateral benefit across many studies evaluating spatial hearing, speech perception, and listening effort (see, for example, Galvin et al., 2011; Sparreboom et al., 2010; van Deun et al., 2009a). Relationships between the parent ratings and objectively measured benefit were not examined as

such data was not available for all children. The lack of a significant relationship between parent ratings and the demographic factors of age at bilateral implantation and time between CIs is at odds with some previous research in which objectively measured benefit from BiCIs has been shown to be related to these factors (see, for example, Scherf et al., 2007, 2009; van Deun et al., 2009b). On the other hand, such relationships have not always been identified consistently across or within studies (Smulders et al., 2011; Scherf et al., 2009). For the present participants, their relatively old age at bilateral implantation ( $\geq 4$  yrs) and their relatively long delay between CIs ( $\geq 2.4$  yrs) may have resulted in no relationships. The mean difference in parent ratings between conditions on qualities of hearing items was significantly related to age at first CI. It seems most likely that this relationship was driven by the fact that children who received their first CI at an older age tended to be rated more poorly by their parents on the Section C items in the UniCI(+HA) condition ( $r = -0.45$ ,  $p = 0.05$ ), thus there was more room for improvement in the BiCIs condition.

Hypothesis two was supported by the results for the speech perception and spatial hearing sections of the SSQ-P, and partially supported by those for the qualities of hearing section. Hypothesis two stated that the group performance ratings would be significantly higher in the BiCIs condition compared with the UniCI(+HA) condition for the speech perception scenarios involving group conversation and/or background noise. Performance ratings for the participant group in the BiCIs condition were higher for the three items involving group conversation (A3, A4 and A6). This may have been due to all or some of the following: increased access to the headshadow effect, improved spatial hearing ability, binaural loudness summation, and binaural unmasking. Due to the acoustic shadow cast by the head, the level of a signal is greater at the ear closest to the signal source and, in background noise, the level of noise is reduced at the ear furthest from the noise source. With unilateral sound input, the listener can only take advantage of the headshadow effect if the arrangement of the signal and noise sources is advantageous. With bilateral sound input, such as via BiCIs, the listener can take advantage of the headshadow effect irrespective of the source locations (Galvin et al., 2008; van Deun et al., 2010; Lovett et al., 2010; Murphy et al., 2011). This provides a clear advantage in a group conversation as the speakers will be in various locations relative to the listener. The improvement in spatial hearing ability demonstrated for many children using BiCIs (Beijen et al., 2007; Galvin et al., 2011; Litovsky, 2011; Murphy et al., 2011) will help the listener to locate the speaker in a group

conversation. Directing visual attention towards the speaker is socially appropriate, but also gives access to visual cues, such as lip movements and body language, and may provide an improved signal-to-noise ratio. The benefit to speech perception resulting from an improved ability to correctly orientate towards the speaker when using BiCIs has been objectively demonstrated for adults (van Hoesel, 2013). Given that contributions to group conversations may overlap in time, improved spatial hearing may also help the listener to segregate multiple speech streams, thus aiding the interpretation of more than one speech stream at a time and/or the prioritisation of the signal of primary interest. Binaural loudness summation results in a perceived increase in loudness when the signals arriving at each ear are combined. Binaural unmasking occurs when comparison of the two different signals arriving at each ear enables the formation of a central representation of the auditory input which has a superior signal-to-noise ratio to that available at either ear (Moore, 1989). The potential contribution of these latter two effects is smaller, and it is difficult to determine the degree to which children using BiCIs benefit from these effects; for example, a number of studies have provided contradictory evidence for the occurrence of binaural unmasking (Galvin et al., 2007; Scherf et al., 2007; Van Deun et al., 2009a; Van Deun et al., 2010).

The items involving group conversation in background noise (A4 and A6) generated the lowest UniCI(+HA) condition ratings for the group across the speech perception section. This result is consistent with those of previous studies in which parents, teachers and adolescents have all identified group conversations as particularly difficult for CI users, with some emphasising the additional difficulties caused by the presence of background noise (Bat-Chava & Deignan, 2001; Punch & Hyde, 2011; Rich et al., 2013; Wheeler et al., 2007). The significantly higher performance ratings in the BiCIs condition for the present children in group conversations are consistent with previous anecdotal reports that children function better and are more confident in group communication when using BiCIs (Galvin et al., 2014; Redfern & McKinley, 2011), and with parent reports that the use of BiCIs predicts positive communication, social, and academic outcomes, including participation in a mainstream classroom (Hyde et al., 2011). The importance of an improved ability to participate in group conversations cannot be overstated. Participating in conversation facilitates the acquisition of phonological, lexical, morphological, and syntactic knowledge, as well as the development of pragmatic skills (Veneziano, 2010). Conversation within families has a significant impact on children's development. For example,

patterns of family narrative interactions have been shown to be related to children's development of a sense of self-worth (Bohanek et al., 2006), and early conversational experience about invisible beliefs, which will occur primarily within the family, contributes to the development of a theory of mind (Peterson & Siegal, 1999; Woolfe et al., 2002). Conversation occurs more frequently amongst friends than nonfriends (Newcomb & Bagwell, 1995), suggesting that it also plays a role in the development and maintenance of friendships. The value of friendships in facilitating emotional and social growth, and in developing a positive self-image has been well established (Ladd et al., 1996; Von Salisch, 2001).

As noted, the results for the speech perception scenarios involving a single speaker in background noise (items A1, A5, and A8) supported hypothesis two, with higher ratings for the group in the BiCIs condition. In everyday life, these scenarios would typically have involved spatial separation of the speech and noise sources, resulting in a different signal-to-noise ratio at each ear. Thus the listener would benefit primarily from the headshadow effect, and could possibly also benefit from binaural summation and binaural unmasking. Improved spatial hearing may also have made a contribution through an increased ability to segregate sound streams and to thus focus on the signal of interest.

Although not predicted by hypothesis two, performance ratings were also significantly higher in the BiCIs condition for the single-speaker scenarios involving reverberation (item A7) or a quiet background (item A2). Although there are no studies in the literature which have evaluated children using CIs, listeners with normal hearing have demonstrated higher tolerance for reverberation when listening with two ears compared with one (Nábělek & Robinson, 1982). At a simple level, increased access to the headshadow effect through the use of BiCIs would be advantageous in some reverberant situations: if one ear is ipsilateral to a solid surface, the headshadow effect will reduce the impact of more direct reverberations at the contralateral ear. For item A2, significantly higher ratings in the BiCIs condition were not expected due to ceiling effects. Nevertheless, there is some objective evidence of improved speech perception in quiet for children using BiCIs, possibly due to binaural loudness summation and redundancy (Gordon & Papsin, 2009; Scherf et al., 2007; Strøm-Roum et al., 2012).

The spatial hearing section results supported hypothesis two, with higher ratings for the group in the BiCIs condition for all items. The generally very low ratings in the UniCI(+HA) condition indicate the children's performance was typically perceived as poor. The exception was item B3. The wide range of results was due to some children using voice recognition to easily identify the parent's location. The degree of difference between the median group rating in the UniCI(+HA) versus the BiCIs conditions ranged from 2.5 to 6; this was generally greater than the 0.75 to 2.5 difference for the speech perception section. These results are consistent with the objective evidence of improved lateralisation and localisation skills (Galvin et al., 2011; Grieco-Calub & Litovsky, 2010; Lovett et al., 2010; Van Deun et al., 2009b) and with the subjective reports of improved localization in daily life for children using BiCIs (Redfern & McKinley, 2011; Sparreboom et al., 2012b; Scherf et al., 2009). Improved performance in the types of scenarios described in the spatial section will benefit communication in daily life, and will also provide valuable functional benefits related to convenience and safety.

The qualities of hearing section results provided partial support for hypothesis two, with higher ratings for the group in the BiCIs condition for scenarios involving the segregation of sounds (C1 and C2), but not for those focussed on listening effort (C7 and C8). The ability to identify the location of sound sources helps the listener to segregate sound streams, and thus to focus on a particular signal of interest. Improved localisation skills with BiCIs for the present group may have resulted in an increased ability to segregate sounds. Reduced listening effort was expected as a consequence of improved speech perception in noise and spatial hearing. For eight adolescents using BiCIs, objective testing demonstrated reduced listening effort for the group and for 38% of individuals (Hughes & Galvin, 2013). In the present study, the BiCIs condition ratings for item C7 (effort in conversation) were at least two points higher than the UniCI(+HA) condition ratings for a similar proportion of individuals (30%), although, as noted, the group difference was not significant. Listening effort may not have been reduced for some participants and/or an actual reduction in effort experienced by the child may not have been evident to the parent providing the rating.

As already discussed, previous studies in which the SSQ-P was administered compared results generally for the overall group and for each SSQ-P section only. Although direct comparisons with those results are not possible, some general comments can be made. In line with the present

results, previous authors reported group performance ratings in the BiCIs condition were consistently higher for the spatial hearing section (Beijen et al., 2007; Kim et al., 2013; Lovett et al., 2010; Sparreboom et al., 2012a), and that differences between device conditions were most often greatest for this section (Beijen et al., 2007; Lovett et al., 2010; Sparreboom et al., 2012a). Also consistent with the present results, higher group performance ratings in the BiCIs condition for the speech perception section were reported for both of the within-participant comparisons (Kim et al., 2013; Sparreboom et al., 2012a). Higher ratings were also reported for the one between-participant comparison which involved a large participant group (Lovett et al., 2010), but not for the two comparisons which involved small samples (Beijen et al., 2007; Sparreboom et al., 2012a). Finally, the pattern of higher group performance ratings in the BiCIs condition was weakest for the qualities of hearing section. In the previous studies, ratings were higher only for the two within-participant comparisons (Kim et al., 2013; Sparreboom et al., 2012a). In the present study, the proportion of individuals with significantly higher BiCIs condition ratings was lower (45%) than for the other sections, and a ratings difference between conditions was found for only three individual items.

In summary, parent ratings of their child's performance on each of the speech perception, spatial hearing, and qualities of hearing sections of the SSQ-P were significantly higher in the BiCIs condition for 45 to 65% of individual children, with 75% of parents perceiving change in at least one area of performance. Ratings were generally not related to age at first CI, time between CIs, or age at bilateral implantation, although the range of these factors was restricted. For the group, parent ratings were significantly higher in the BiCIs condition for all of the speech perception and the spatial hearing items, but for only three of the qualities of hearing items. These results were generally as predicted, although BiCI condition ratings were higher across a broader range of speech perception scenarios than expected, and ratings were not higher for listening effort-related scenarios. The pattern of results, both in terms of the relative ratings of performance across scenarios of varying difficulty and the change in ratings between conditions, suggests that robust data was provided by the SSQ-P.

These results will be valuable for families considering sequential bilateral implantation by providing more detailed information about expected benefit. They will also be useful to clinicians in guiding postoperative discussions about benefit. Identifying specific areas in which

benefit is being gained may help to motivate a child or young adult and their family to work to further improve listening skills with a second CI and/or to achieve more consistent usage of both CIs. Identifying a lack of benefit in expected areas may suggest that an individual would benefit from additional intervention. If future research can identify the factors which influence the benefit gained by individuals from using BiCIs in their daily listening, this will provide even more important information for families and clinicians. Larger participant groups and the inclusion of children implanted at a younger age and with less or no delay between CIs will allow a more powerful analysis than that reported here.

Supplemental Digital Content 1: Listening scenarios in the each of the three sections of the Speech, Spatial and Qualities of Hearing Scale for Parents.

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