Contralateral acoustic hearing aid use in adult unilateral cochlear implant recipients: Current provision, practice, and clinical experience in the UK

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Objectives: The study surveyed practising cochlear implant (CI) audiologists with the aim of: (1) characterizing UK clinical practice around the management and fitting of a contralateral hearing aid (HA) in adult unilateral CI users (`bimodal aiding’); (2) identifying factors that may limit the provision of bimodal aiding; and (3) ascertaining the views of audiologists on bimodal aiding.

Methods: An online survey was distributed to audiologists working at the 20 centres providing implantation services to adults in the UK.

Results: Responses were received from 19 of the 20 centres. The majority of centres reported evaluating HAs as part of the candidacy assessment for cochlear implantation. However, a majority also indicated that they do not take responsibility for the contralateral HA following implantation, despite identifying few practical limiting factors. Bimodal aiding was viewed as more beneficial than wearing the implant alone, with most respondents actively encouraging bimodal listening where possible. Respondents reported that fitting bimodal devices to take account of each other’s settings was potentially more beneficial than independently fit devices, but such sympathetic fitting was not routine practice in any centre.

Discussion: The results highlight some potential inconsistencies in the provision of bimodal aiding across the UK as reported by practising audiologists. The views of audiologists about what is best practice appear to be at odds with the nature and structure of the services currently offered.

Conclusion: Stronger evidence that bimodal aiding can be beneficial for UK patients would be required in order for service providers to justify the routine provision of bimodal aiding and to inform guidelines to shape routine clinical practice.

Keywords: Cochlear implants, Bimodal aiding, Acoustic hearing aids, Clinical practice of bimodal fitting, Binaural hearing, Bimodal benefits, Sympathetic bimodal fitting, Bimodal listening

Introduction

Cochlear implantation was originally devised as a method for restoring a sensation of sound in bilateral sensorineural hearing impairment where the degree of loss was total or profound (Ramsden, 2013). A consensus statement from the US National Institutes of Health (NIH) in the late 1980s demonstrated that cochlear implantation was largely restricted to individuals who could derive no real benefit from acoustic hearing aids (HAs) and no open-set speech discrimination (Kohut et al., 1988). A subsequent NIH consensus statement acknowledged that listening performance of some adults with a severe-to-profound hearing impairment was poorer than that of adults with a more profound impairment but who used a cochlear implant (CI) (Gates et al., 1995). As a result, a relaxation of candidacy criteria was recommended to include individuals with up to 30% open-set speech discrimination in their best-aided condition in the US.

At approximately the same time in the UK, a national study group was evaluating outcomes following cochlear implantation in patients who either had no open-set speech discrimination before implantation (`traditional candidates’) or who had some measurable discrimination (`marginal hearing aid users’) (UKCISG, 2004a). The study group concluded that those patients who had some usable residual hearing...
pre-operatively (i.e. non-traditional candidates, or ‘marginal hearing aid users’) can have favourable odds of benefitting from cochlear implantation, particularly those with shorter durations of deafness, and therefore should be considered as candidates for the treatment.

In 2009, the National Institute for Health and Care Excellence (NICE) in the UK reviewed the evidence for the effectiveness and cost-effectiveness of cochlear implantation in adults (NICE, 2009). As a result of their appraisal of the evidence, NICE recommended unilateral cochlear implantation for adults with a bilateral severe-to-profound sensorineural hearing impairment who derive ‘insufficient’ benefit from acoustic HAs. Insufficient benefit was defined as an inability to report at least 50% of words on an open-set test of speech discrimination in quiet while in their best-aided condition. The effective result of these recommendations was an expansion of the eligibility criteria which led to an associated increase in the number of hearing impaired individuals that would be suitable for the treatment. When the NICE guidance was published, approximately 900 adults were implanted each year across 14 hospitals (NHS, 2012), a level of activity which had increased to 1161 by 2014 across 19 implanting centres (BCIG, 2015). As candidacy criteria in the UK now permit candidates to have measurable open-set speech perception but still restrict implantation to one ear (thus retaining the audiological status of the non-implanted ear), many implant recipients in the UK now have measurable residual hearing and potentially aidable thresholds in their non-implanted ear.

Bimodal aiding is the practice of providing and fitting an acoustic HA in one ear and a CI in the other ear. Improvements in listening abilities from using both devices over using the CI alone (bimodal benefits) have been widely documented, and are thought to reflect the integration of low frequency acoustic cues from the HA with higher frequency cues from the CI (Gantz and Turner, 2003). Despite the fact that unilateral cochlear implantation is the current treatment for adults with severe-to-profound hearing losses in the UK (NICE, 2009), the restoration of binaural hearing whether through bilateral implantation or bimodal listening has been recommended for this patient group (point 1.1; NHS, 2013).

A systematic review of the evidence for bimodal aiding in adults found that wearing a contralateral HA in addition to a CI can provide benefits to speech perception, particularly in the presence of background noise (Olson and Shinn, 2008). These bimodal benefits to speech perception have been observed even when the information accessible to the non-implanted ear cannot support any useful speech perception on its own (Zhang et al., 2010), suggesting that there may be supra-additive benefits from combining acoustic with electric hearing. Other studies have suggested that the benefits are not supra-additive but simply reflect the fact that CI users may be able to integrate electric and acoustic information optimally (Micheyl and Oxenham, 2012). Bimodal aiding has also been shown to improve music perception (Kong et al., 2004) and the naturalness of speech (Sucher and McDermott, 2009), and may improve sound localization in some listeners (Dunn et al., 2005). The evidence has led some to recommend that bimodal aiding should be offered routinely when listeners are able to make some use of both devices (Ching et al., 2004).

The size of bimodal benefit that patients receive has been found to relate to the level of acoustic hearing in their non-implanted ear (Zhang et al., 2013). Accordingly, many studies that have demonstrated bimodal benefits have done so in patients who have access to a level of hearing in their non-implanted ear that is readily aidable using an acoustic HA (Morera et al., 2005; Yoon et al., 2012) and therefore greater than that typically available to patients in the UK who meet NICE criteria. Despite this, there is evidence that UK patients report benefits from wearing a HA in addition to their CI and may derive benefits to speech perception from doing so (Visram, 2012). Other bimodal benefits that have been observed in UK patients include some ability to distinguish emotions in spoken sentences and an improved ability to determine the location of sounds (Goman, 2014).

The importance of an appropriately fit HA for use in combination with a CI has been well documented (Ching et al., 2004; Dunn et al., 2005; Gifford et al., 2007, 2010, Kong et al., 2005; Mok et al., 2006). To date, professional bodies in the UK including the British Cochlear Implant Group (BCIG), the British Society of Audiology (BSA) and the British Academy of Audiology (BAA) have yet to issue guidance on the provision of HAs that are to be used simultaneously with a CI in the other ear, and how the two devices should be fit to work sympathetically together. It is therefore unclear whether clinicians providing CI services in the UK undertake HA evaluations or consider the potential benefits of bimodal aiding when assessing candidacy, when considering which ear should be implanted to maximize benefit, when fitting the CI, or when reviewing progress following implantation. The aim of this study was therefore to survey audiologists across UK adult CI centres about their current practice around bimodal aiding. The objectives of the survey were:

1. To describe current clinical practice in the UK around bimodal aiding in adults;
2. to identify factors potentially limiting clinical practice around bimodal aiding;
3. to characterize audiologists’ views of bimodal aiding.
Methods

Design

The survey (Supplementary Material 1) was designed to characterize clinical practice around bimodal aiding by following the temporal progression of a patient through the care pathway from candidacy assessment through to the choice of ear for implantation, initial activation of the CI, and post-implantation follow up. Questions types were varied and included: (i) scaling to estimate patient numbers or importance ratings; (ii) agreement/disagreement using a five-point Likert scale; (iii) frequency of occurrence using both yes/no and always/sometimes/rarely/never response sets (reflecting degree of certainty); and (iv) open-ended questions where free text responses were permitted.

Most questions were designed to elicit a response, and respondents were not permitted to proceed to the next question until a response to the current question had been provided. Responses to open-ended questions were always optional. Conditional question pathways were included so that each respondent was presented with a set of questions that were deemed appropriate based on their previous responses. For example, questions about the manner in which HAs are fit at the candidacy assessment stage were not presented to respondents who had previously indicated that they never fit HAs at that stage of the care pathway.

Distribution

The survey was distributed online using the SurveyMonkey software (https://www.surveymonkey.com/). The survey was targeted at audiologists working at CI centres within the UK. An invitation to complete the online survey was distributed to every BCIG member indicating it was for the attention of audiologists working with adult patients. The introductory text of the survey indicated that only those who work with adult patients should complete the survey. No option was given to complete the survey on paper. Sixty-six audiologists were registered with audiology-related job titles on the BCIG mailing list at the time of mailing (January 2015), which included representatives from the 20 UK CI centres that work with adult patients. Programme coordinators were also invited to forward the survey to any audiologist who may not be a member of the BCIG. A follow up letter and poster for placement in communal areas such as staff rooms was sent to the coordinator of each CI centre 1 month after the initial invitation was sent. After a further 3 months, coordinators of CI centres who had not yet contributed were sent a reminder email or were contacted by telephone.

Procedure

Respondents were informed that the purpose of the survey was to investigate current practice around evaluating, fitting and reviewing patients who use (or could use) bimodal devices. Respondents were asked to name the CI centre in which they worked. This information was collected to determine the geographical distribution of responses and to assess whether the results were likely to be representative of current practice across the UK. Respondents were informed that their responses would be strictly anonymous. Accordingly, in reporting the results individual responses have not been associated with any particular CI centre. While acknowledging that every patient is an individual, respondents were asked to think about the things they would typically do and to focus on their practice within the last 5 years.

Analysis

The survey was divided into three sections based on relevance to the study objectives. Sections were not equal in length, given the greater complexity of certain aspects of clinical practice than others. No question contributed to more than one section. The number of responses varied across questions due to the use of conditional question pathways and the fact that respondents were not required to answer all questions. Where possible, individual responses were converted to a binary outcome by grouping them into one of two categories (e.g. agree/disagree, yes/no, etc.). Responses were then summarized as the proportion of centres from which positive responses were received and as the proportion of individuals who responded positively. Ninety-five percent confidence intervals were calculated for each of these proportions (Newcombe, 1998).

The terms ‘majority’ and ‘minority’ were applied only to proportions that were found to be significantly greater than or less than 50% of respondents, respectively. For example, if data were available from 19 centres on a particular question, a proportion of 26% or less (five centres or fewer) was interpreted as a ‘minority’ (upper 95% confidence interval of proportion = 48.8%) and a proportion of 74% or more (at least 14 centres) was interpreted as a ‘majority’ (lower 95% confidence interval of proportion = 51.2%). Where questions contained an estimation of the frequency of a clinical activity or procedure (always/often/sometimes/rarely/never), practice was considered routine if respondents selected the ‘always’ or ‘often’ options. The statistical significance of the difference between two proportions was calculated using McNemar’s test (McNemar, 1947).

Results

Nineteen of the 20 centres contributed to the survey resulting in a centre response rate of 95%. Complete
Table 1  A list of the UK adult cochlear implant centres which contributed to the survey dataset and the numbers of respondents from each

| Participating centres                                                                 | Number of responses |
|--------------------------------------------------------------------------------------|---------------------|
| Belfast Cochlear Implant Centre                                                       | 1                   |
| Cardiff Adult Cochlear Implant Programme                                              | 1                   |
| Dublin Cochlear Implant Programme                                                     | 1                   |
| Emmeline Centre, Cambridge                                                           | 1                   |
| The Richard Ramsden Centre for Hearing Implants (Manchester)                         | 3                   |
| The Midlands Hearing Implant Programme (Adults’ Service)                              | 3                   |
| North Wales Cochlear Implant Programme                                               | 1                   |
| Nottingham Auditory Implant Programme                                                | 3                   |
| The Oxford Cochlear Implant Programme                                                | 1                   |
| Portland Hospital Cochlear Implant Programme                                          | 1                   |
| RNTNE Adult Implant Programme                                                        | 1                   |
| Scottish Cochlear Implant Programme                                                   | 1                   |
| South Wales Cochlear Implant Programme                                               | 1                   |
| St George’s Hospital Auditory Implant Service                                        | 1                   |
| St Thomas’ Hospital Hearing Implant Centre                                           | 1                   |
| University of Southampton Auditory Implant Service                                   | 7                   |
| West of England Hearing Implant Programme                                            | 2                   |
| Yorkshire Auditory Implant Service (Bradford)                                        | 1                   |
| Yorkshire Auditory Implant Service (Sheffield)                                       | 1                   |
| Total number of completed responses with identifiable affiliation                     | 33                  |
| Total number of incomplete responses without identifiable affiliation                 | 5                   |
| Total number of responses                                                             | 38                  |

The 19 participating centres represent a response rate of 95%. The centre not listed either did not participate in the survey or did not complete the survey to the point where the centre name was requested.

Table 2  Mean responses to questions about current clinical practice in the UK relating to HA management.

| HA management during candidacy assessment                                  | No. centres (%; 95% CI) | No. respondents (%; 95% CI) |
|---------------------------------------------------------------------------|--------------------------|-----------------------------|
| conduct HA evaluations as part of the candidacy assessment                 | 18 (95; 75–99)           | 28 (74; 58–85)              |
| routinely check HA fittings in patients attending for assessment          | 14 (78; 55–91)           | 21 (75; 57–87)              |
| check HA fittings in every HA user during assessment                      | 11 (61; 39–90)           | 16 (57; 39–73)              |
| routinely attempt a HA fitting in a candidate with no HAs                | 15 (83; 61–94)           | 24 (86; 69–94)              |
| routinely attempt to fit a HA to a single non-aided ear                  | 11 (61; 39–90)           | 14 (50; 33–67)              |
| use a combination of HA evaluation methods                               | 17 (94; 74–99)           | 23 (82; 64–92)              |
| HA management following implantation                                      |                          |                             |
| routinely take responsibility for the contralateral HA                   | 5 (26; 12–49)            | 6 (18; 9–34)                |
| would refer to a different audiologist for HA issues                      | 15 (79; 57–91)           | 27 (82; 66–91)              |
| evaluate the contralateral HA during the first 12 m of CI use            | 8 (42; 23–64)            | 10 (30; 17–47)              |
| attempt to re-fit a HA the patient had stopped wearing                   | 6 (32; 15–54)            | 6 (18; 9–34)                |
| routinely attempt a HA fitting in an unabaided contralateral ear         | 0 (0; 0–17)              | 0 (0; 0–10)                 |
| only fit a HA to an unabaided contralateral ear at patient request        | 9 (47; 27–68)            | 10 (30; 17–47)              |
| routinely review the HA fitting after 12 m of CI use                     | 3 (16; 6–38)             | 3 (9; 3–24)                 |
| use the same combination of HA evaluation methods as pre-CI              | 9 (47; 27–66)            | 10 (33; 19–51)              |

The number of CI centres from which positive responses were received to each question is reported together with the percentage and its 95% confidence interval. The table also lists the number of respondents who responded positively, also expressed as a percentage with 95% confidence intervals. The use of bold type indicates that a result represented a significant minority (<50%) or majority (>50%) of CI centres and/or respondents.
HA management during candidacy assessment

Respondents estimated that 87% of patients who attend for candidacy assessment wear a HA in at least 1 ear (95% confidence interval: 83–92%; Table 2). All but one centre reported that they do conduct HA evaluations as part of the candidacy assessment and a majority of those centres (14 out of 18) reported checking HA fittings routinely as part of this evaluation. The fact that some respondents in those 14 centres indicated that they do not check HA fittings routinely could suggest some level of inconsistency within centres but may also simply reflect the division of responsibilities among staff. Eleven centres indicated that they would check the HA fitting in every patient who attended wearing HAs, but this did not represent a majority.

The need for HA fitting and evaluation appeared to be judged on an individual basis. When presented with the scenario of a CI candidate who does not wear HAs but has measurable hearing thresholds or a history of recent HA usage, a majority of centres (83%) indicated they would routinely attempt to fit HAs. When presented with an alternative scenario of a candidate attending wearing a single HA, the number of centres that reported routinely attempting a HA fitting in the unaided ear dropped to 61%, which did not represent a majority. Two respondents from a single CI centre commented that they would rarely attempt to fit a HA to the unaided ear as the result would be unlikely to affect the candidacy decision, where open-set speech discrimination scores in the quiet when in their best-aided condition must be <50% (NICE, 2009).

A variety of HA fitting and verification methods were reported including fitting to a prescription target (64%), Real Ear Measurement (61%), aided threshold measurement (50%), and speech discrimination testing (50%). The majority of centres reported using a combination of methods.

HA management following implantation

Respondents estimated that 58% of patients who received their CI within the last 5 years wear a contralateral HA at initial activation of the CI (95% confidence interval: 51–64%), but hypothesized that only 41% of this group would still be wearing the HA after 5 years of implant use (mean decrease as a proportion of all CI users of 33%; 95% confidence interval 28–38%; Table 2). Only a minority of centres indicated that they take full responsibility for the maintenance of the contralateral HA once the CI is activated despite the fact that the majority of centres reported routinely conducting HA reassessments prior to implantation, and may have fitted the aid during the assessment. Instead, a majority of centres indicated that they refer patients elsewhere for their ongoing HA maintenance.

Table 3 Mean responses to questions about current clinical practice in the UK relating to bimodal fitting, outcome measurement, and advice

| Question                                                                 | No. centres (%; 95%CI) | No. respondents (%; 95%CI) |
|--------------------------------------------------------------------------|------------------------|-----------------------------|
| **Sympathetic bimodal fitting**                                          |                        |                             |
| Follow an agreed bimodal switch-on protocol                              | 1 (5; 1–25)            | 1 (3; 1–15)                 |
| Take HA parameters into account when programming the CI                  | 4 (21; 9–43)           | 4 (12; 5–27)                |
| Match fitting parameters, e.g. frequency ranges of HA and CI balance the CI and HA for loudness | 0 (0; 0–17)            | 0 (0; 0–10)                 |
| At subsequent review appointments: Numbers who...                        |                        |                             |
| Follow an agreed bimodal programming protocol                            | 1 (5; 1–25)            | 2 (6; 2–20)                 |
| Take HA parameters into account when programming the CI                  | 3 (16; 6–38)           | 3 (9; 3–24)                 |
| Match fitting parameters, e.g. frequency ranges of HA and CI balance the CI and HA for loudness | 2 (11; 3–31)           | 3 (9; 3–24)                 |
| At initial activation: Numbers who...                                    |                        |                             |
| Routinely measure CI-only listening outcomes                             | 18 (95; 75–99)         | 27 (82; 66–91)              |
| Routinely measure bimodal listening outcomes                             | 12 (63; 41–81)         | 17 (52; 35–67)              |
| Routinely measure HA-only listening outcomes                             | 5 (26; 12–49)          | 5 (15; 7–31)                |
| Choose specific outcome measures to measure bimodal benefit             | 4 (33; 14–61)          | 4 (24; 10–47)               |
| **Advice given to patients**                                            |                        |                             |
| At initial activation: Numbers who...                                    |                        |                             |
| Recommend intermittent use of the HA at first                            | 13 (68; 46–85)         | 19 (58; 41–73)              |
| Recommend not wearing the HA until 3 months post-CI                      | 4 (21; 9–43)           | 5 (15; 7–31)                |
| Recommend both devices be worn together from the start                   | 3 (16; 6–38)           | 5 (15; 7–31)                |
| Leave it to the patient to decide if bimodal aiding is beneficial        | 4 (21; 9–43)           | 4 (12; 5–27)                |
| At subsequent review appointments: Numbers who...                        |                        |                             |
| Intervene actively encourage established CI users to wear a HA           | 18 (95; 75–99)         | 31 (94; 80–98)              |

The number of CI centres from which positive responses were received to each question is reported together with the percentage and its 95% confidence interval. The table also lists the number of respondents who responded positively, also expressed as a percentage with 95% confidence intervals. The use of bold type indicates that a result represented a significant minority (<50%) or majority (>50%) of CI centres and/or respondents.
A minority of centres indicated that they routinely conduct a contralateral HA evaluation within the first 12 months of CI use, and only three centres reported routinely reviewing the HA fitting after 12 months of CI use. Six centres indicated that they would attempt to re-fit a contralateral HA that a CI user had stopped wearing following implantation but this represented a minority view. All centres indicated that they would not routinely fit a new HA in an unaided contralateral ear within the first 3 months after CI activation, even if it had potentially aidable thresholds, although nine centres indicated that they would consider it but only at the patient’s request. The post-operative HA fitting and verification methods reported by respondents were notably different to the methods chosen pre-operatively, with only 33% of respondents selecting the same combination of methods at the two time intervals.

**Sympathetic bimodal fitting**

At initial CI activation, only one centre reported an agreed protocol for ‘bimodal switch-on’ in the clinic; i.e. consideration of both devices when creating the first CI programme (Table 3). Four centres did report taking the HA parameters into account when first activating the CI, but no centre indicated making any attempt to match device parameters such as compression settings or frequency allocations at this stage. Eleven centres reported attempting to match the two devices for loudness at the CI fitting stage but this did not represent a majority.

There was minimal evidence that devices are fit sympathetically at subsequent CI review appointments. Only one centre, which notably was not the centre that reported using a bimodal switch-on procedure above, reported following a protocol for programming bimodal patients in the clinic. Only a minority of centres reported taking the parameters of the HA into account when deciding how to reprogramme the CI, and only one respondent was consistent in using these parameters at both switch-on and subsequent reviews. Only two centres indicated that they attempt to match device parameters such as compression settings or frequency allocations at CI review appointments. However, a majority of centres reported balancing loudness across the two devices at review appointments.

In summary, inconsistencies in practices relating to bimodal fitting at both initial and subsequent CI programming appointments were apparent. It would therefore appear likely that any programming adjustments related to improving bimodal listening are made to the implant only and not to the HA, given that the majority of centres do not routinely adjust HA fittings post-implantation.

**Bimodal outcome measurement**

When a bimodal listener attends for a performance review, all but one centre reported routinely measuring listening outcomes using the CI alone, 12 centres (not a majority) reported routinely measuring bimodal listening outcomes, while a minority of centres reported routinely measuring outcomes from the HA alone following implantation (Table 3). Only seven centres reported that they follow an agreed protocol for measuring bimodal benefit in the clinic, and three centres reported rarely or never measuring bimodal outcomes.

Of the 12 centres that report measuring bimodal outcomes routinely, four indicated that they choose additional listening tests specifically to measure bimodal benefit that would not normally be used with a unilateral CI listener. A free text box was provided for respondents to list any test used specifically to measure bimodal benefit. The following tests were listed: BKB sentences in adaptive noise test, the Star test (Sentence Test with Adaptive Randomized Roving levels) test (Joffo and Boyle, 2010), multiple speaker sound localization, and the CRM (Coordinate Response Measure) sentence test (Kitterick et al., 2010, 2011).

**Patient advice**

When a patient attends for initial activation wearing a HA in the non-implanted ear, advice about how to use the HA in addition to the CI was inconsistent across centres (Table 3). Only a minority of centres recommend that both devices be worn together from the first day that the CI is activated, with 68% recommending intermittent use of the HA at first to allow time for CI-only listening. A separate minority reported advising patients not to wear the HA until

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**Table 4 A summary of clinical practice at different stages of the temporal clinical care pathway**

| Practice                          | Pre-implant | Initial activation | Post-implant |
|-----------------------------------|-------------|--------------------|--------------|
| Hearing aid management            | ✓ (2)       | ✓ (2)              | ✓ (2)        |
| Sympathetic bimodal fitting       | –           | ✓ (3)              | ✓ (3)        |
| Advice to patients on bimodal aiding | –          | ? (3)             | ✓ (3)        |
| Bimodal outcome measurement       | –           | –                  | ? (3)       |

A tick represents practice that is routine, i.e. conducted by a majority of respondents and centres; a cross represents practice that is not routine, i.e. conducted only by a minority of respondents and centres, and a question mark represents inconsistency in practice across respondents and centres. The table numbers that contain these data are shown in brackets.
they have been using their CI for around 3 months. Four centres indicated that they would not make recommendations about contralateral HA use and would leave it to the patient to decide.

In spite of the uncertainties about HA use evident at initial CI activation, a majority of centres (95%) reported actively encouraging CI users to wear a contralateral HA once they had used their implant for at least 3 months. No respondent reported actively discouraging contralateral HA usage after an initial 3-month CI acclimatization period.

**Interim summary**

An overview of the consistencies and inconsistencies of clinical practice derived from this section is shown in Table 4. Centres almost universally reported evaluating HAs during candidacy assessment, a practice that is consistent with national guidance that requires the speech perception abilities of candidates to be assessed in the best-aided condition (NICE, 2009). However, some variability in reported practice both within and between centres was apparent. The current reports suggest that most centres do not maintain the long term care of the contralateral HA, do not routinely optimize bimodal aiding through evaluating or re-fitting the HA post-operatively, and do not practise sympathetic bimodal fitting. The focus of the audiologist seems primarily on optimizing the CI. The two devices are therefore likely to be programmed independently after implantation, on separate occasions and not necessarily by the same person or at the same centre. While there is reportedly some uncertainty about how to advise patients on bimodal listening at initial CI activation, most centres appear to actively encourage HA during later stages of CI use, implying a mismatch between their advice to listen bimodally and their clinical practice to optimize it.

**Section 2: factors limiting bimodal practice**

Table 5 lists the proportion of CI centres and individual responses who agreed or disagreed with statements about factors that might limit the provision and optimization of bimodal devices and their associated confidence intervals.

### HA management

During candidacy assessment. Numbers who indicated...

|                                | No. centres (%; 95% CI) | No. respondents (%; 95% CI) |
|--------------------------------|-------------------------|-----------------------------|
| A lack of staff expertise in HA fitting | 8 (42; 23–64)           | 18 (50; 34–66)             |
| A lack of time                  | 3 (16; 6–38)            | 4 (11; 4–25)               |
| A lack of available audiologists | 6 (32; 15–54)           | 8 (22; 12–38)             |
| A lack of rooms/equipment       | 5 (26; 12–49)           | 9 (25; 14–41)             |
| Patients have insufficient residual hearing | 1 (5; 1–25)           | 1 (3; 0–14)               |

**During initial activation. Numbers who indicated...**

|                                | No. centres (%; 95% CI) | No. respondents (%; 95% CI) |
|--------------------------------|-------------------------|-----------------------------|
| A lack of time                  | 13 (68; 46–85)          | 17 (52; 35–67)             |
| A lack of equipment             | 5 (26; 12–49)           | 10 (30; 10–47)             |

**During subsequent reviews. Numbers who indicated...**

|                                | No. centres (%; 95% CI) | No. respondents (%; 95% CI) |
|--------------------------------|-------------------------|-----------------------------|
| A lack of time                  | 11 (59; 36–77)          | 15 (45; 30–62)             |
| A lack of rooms/equipment       | 7 (37; 19–59)           | 11 (33; 20–50)             |
| A lack of staff expertise in HA fitting | 5 (26; 12–49)           | 14 (42; 27–59)             |
| A lack of available audiologists | 9 (47; 27–68)           | 18 (55; 38–70)             |

**Bimodal outcome measurement Numbers who indicated...**

|                                | No. centres (%; 95% CI) | No. respondents (%; 95% CI) |
|--------------------------------|-------------------------|-----------------------------|
| A lack of time                  | 9 (47; 27–68)           | 12 (36; 22–53)             |
| A lack of staff expertise       | 4 (21; 9–43)            | 5 (15; 7–31)               |
| A lack of equipment             | 6 (32; 15–54)           | 6 (18; 9–34)               |

**Sympathetic bimodal fitting Numbers who indicated...**

|                                | No. centres (%; 95% CI) | No. respondents (%; 95% CI) |
|--------------------------------|-------------------------|-----------------------------|
| A lack of time to fit both devices in the same session | 11 (58; 36–77) | 17 (52; 35–67) |
| A lack of guidelines on optimizing bimodal fittings | 12 (63; 41–81) | 18 (55; 38–70) |

The number of CI centres from which positive responses were received to each question is reported together with the percentage and its 95% confidence interval. The table also lists the number of respondents who responded positively, also expressed as a percentage with 95% confidence intervals. The use of bold type indicates that a result represented a significant minority (<50%) or majority (>50%) of CI centres and/or respondents.
How to advise patients on bimodal listening

Numbers who indicated it is clinically useful to measure bimodal benefit

18

16

Bimodal benefit

Consideration of bimodal aiding when choosing the CI ear

16

16

it is beneficial to optimize the contralateral HA

15

13

During candidacy assessment.

Numbers who indicated it is beneficial to optimize HA management when to reintroduce the HA post-CI maximizing bimodal benefit

15

10

18

Further guidance

Numbers who indicated a need for guidance on...

how to optimize the two devices to work better together

13

10

18

Table 6 Mean responses to questions about audiologists’ views of bimodal aiding

| HA management                               | No. centres (%; 95%CI) | No. respondents (%; 95%CI) |
|---------------------------------------------|------------------------|---------------------------|
| During candidacy assessment. Numbers who indicated it is the role of the CI audiologist to evaluate Has | 13 (68; 46–85)         | 15 (42; 27–58)            |
| it is beneficial to optimize Has            | 18 (95; 75–99)         | 33 (92; 78–97)            |
| During subsequent reviews. Numbers who indicated it is the role of the CI audiologist to evaluate contralateral Has it is beneficial to optimize the contralateral HA | 15 (79; 51–88) | 20 (61; 50–80) |
| Bimodal benefit                            |                        |                           |
| Consideration of bimodal aiding when choosing the CI ear | 16 (84; 62–94) | 21 (64; 47–48) |
| bimodal aiding is more beneficial than CI-alone | 16 (84; 62–94) | 28 (85; 69–93) |
| it is clinically useful to measure bimodal benefit | 18 (95; 75–99) | 30 (91; 76–97) |
| Sympathetic bimodal fitting                 |                        |                           |
| Numbers who indicated sympathetic device fitting could improve outcomes | 16 (84; 62–94) | 27 (82; 66–91) |
| a recently re-fit HA is more beneficial than an older fitting | 15 (79; 57–91) | 26 (79; 62–89) |
| wearing a previously-fit HA can still provide bimodal benefits | 16 (84; 62–94) | 26 (79; 62–89) |
| Further guidance                            |                        |                           |
| Numbers who indicated a need for guidance on... |                   |                           |
| maximizing bimodal benefit                  | 18 (100; 82–100)       | 31 (97; 85–99)            |
| optimizing bimodal fitting                  | 16 (89; 67–97)         | 29 (91; 76–97)            |
| identifying bimodal candidates              | 14 (78; 55–91)         | 23 (72; 55–84)            |
| measuring bimodal benefit                   | 16 (89; 67–97)         | 28 (88; 72–95)            |
| when to reintroduce the HA post-CI          | 15 (83; 61–94)         | 26 (81; 65–91)            |
| how to advise patients on bimodal listening | 16 (89; 67–97)         | 27 (84; 68–93)            |

The number of CI centres from which positive responses were received to each question is reported together with the percentage and its 95% confidence interval. The table also lists the number of respondents who responded positively, also expressed as a percentage with 95% confidence intervals. The use of bold type indicates that a result represented a significant minority (>50%) or majority (>50%) of CI centres and/or respondents.

The pattern of responses suggests that in centres that currently undertake HA evaluations, resources for managing HAs both during candidacy assessment and after implantation are adequate. In centres that do not currently undertake HA evaluations as part of their service, there appear to be more limitations to overcome including lack of staff expertise, facilities, and possibly also a lack of funding. The fact that respondents from these centres indicated that time is not a limitation suggests that routine HA evaluations would be possible if these logistical factors were addressed. Measurements of bimodal outcomes would also appear to be feasible given the available resources and staff expertise reported by respondents, but longer review appointments may be necessary to ensure that they can be obtained consistently across all patients and centres. The sympathetic fitting of the CI and HA does not appear to be feasible at present due to the time constraints and lack of devices in the same session. A similar number of centres agreed that there is a lack of guidance on how to optimize the two devices to work better together. Additionally, the fact that only a minority of centres reportedly retain responsibility for ongoing care of the contralateral HA post-implantation (Table 2) may also represent a significant factor limiting the provision of sympathetic bimodal fitting.

Interim summary

The pattern of responses suggests that in centres that currently undertake HA evaluations, resources for managing HAs both during candidacy assessment and after implantation are adequate. In centres that do not currently undertake HA evaluations as part of their service, there appear to be more limitations to overcome including lack of staff expertise, facilities, and possibly also a lack of funding. The fact that respondents from these centres indicated that time is not a limitation suggests that routine HA evaluations would be possible if these logistical factors were addressed. Measurements of bimodal outcomes would also appear to be feasible given the available resources and staff expertise reported by respondents, but longer review appointments may be necessary to ensure that they can be obtained consistently across all patients and centres. The sympathetic fitting of the CI and HA does not appear to be feasible at present due to the time constraints and lack of
experience and guidance reported by respondents. Therefore, the data suggest that additional time may also be necessary during certain appointments to ensure that the HA and CI can be maintained and optimized at the same time.

Section 3: respondent views regarding bimodal issues

Table 6 lists the proportion of CI centres and individual respondents who expressed agreement with a range of statements about bimodal aiding and the associated confidence intervals.

HA management

A majority of centres (95%) indicated that it is beneficial both to attempt to optimize HAs during the candidacy assessment stage and to optimize the contralateral HA post-implantation. A majority of centres were also of the opinion that HA optimization was within the role of the CI audiologist both during candidacy assessment and post-operatively (68% and 79%, respectively). Responses from individual audiologists about whether they feel it is within their role to evaluate HA fittings were more mixed both when considering candidacy assessment (42%) and post-operative appointments (61%). It is possible that this apparent variability within centres may have reflected the division of responsibilities among staff.

Respondents were invited to comment on the practicalities of maintaining both devices. Common themes in the responses to this open-ended question indicated that: (i) managing both devices may provide a smoother service for the patient throughout the care pathway; (ii) there are logistical difficulties around HA maintenance as many patients do not live near their CI centre and may prefer to access HA repair services locally; (iii) there are difficulties with funding as CI services may not be commissioned to support and manage HAs; and (iv) there is limited staff expertise of the range of available HAs, software, stock, and spares within CI centres.

Bimodal benefit

When asked to consider both the positives and the negatives of contralateral HA use, the majority of centres (84%) agreed that bimodal aiding provides more benefit than wearing the CI alone. No respondent indicated that wearing the CI alone was more beneficial than bimodal aiding. The majority of centres (84%) reported taking the possibility of bimodal aiding into consideration when choosing which ear to implant, although at an individual level 64% of respondents reported doing so, which did not represent a majority. Respondents were asked to list up to three potential advantages and three potential disadvantages of wearing a contralateral HA in addition to a CI that they had directly observed or heard from patients during their clinical practice. Fig. 1 shows the reported categories of bimodal advantage, the largest of which was sound localization. Fig. 2 shows the reported categories of bimodal disadvantage, the largest of which was related to wearing an earmould.

In spite of the majority of clinics not having an agreed protocol for measuring bimodal outcomes (Section ‘Bimodal outcome measurement’), the majority of centres (95%) reported that it is clinically useful to measure bimodal benefit. Respondents were asked to rate the most useful outcome measures to

Figure 1 Categories of bimodal advantages reported by respondents from direct observation of patients. Error bars plot 95% confidence intervals. A proportion whose right error bar is entirely to the left of the 50% line demonstrates an observation that was observed only by a minority of respondents, whereas a proportion whose left error bar is entirely to the right of the 50% line represents the majority of respondents.

Figure 2 Categories of bimodal disadvantages reported by respondents from direct observation of patients. Error bars plot 95% confidence intervals. A proportion whose right error bar is entirely to the left of the 50% line demonstrates an observation that was observed only by a minority of respondents, whereas a proportion whose left error bar is entirely to the right of the 50% line represents the majority of respondents.
demonstrate bimodal benefit and the proportion of respondents who selected each category of test is shown in Fig. 3. A majority of respondents indicated that measuring speech discrimination in background noise was the most useful clinical measure of bimodal benefit.

Sympathetic bimodal fitting
When asked to compare sympathetic with independent bimodal device fittings, a majority of centres (84%) felt that fitting the devices sympathetically (taking into account each other’s settings) could somehow improve bimodal outcomes over fitting the two devices independently. A majority (79%) also rated a recently refit contralateral HA as more beneficial than one that has not been recently re-fit. However, 84% of centres acknowledged that wearing a contralateral HA that was fit prior to receiving the CI may be sufficient to provide some bimodal benefits. Thus, the responses imply that the use of a contralateral HA, and not necessarily one that has been recently optimized, is better than not using a HA at all.

Further guidance
Respondents from 18 centres completed this section. Every centre indicated that they would welcome guidance on: (1) how to maximize bimodal benefit; (2) how to optimize bimodal fitting; (3) which patients would be most likely to benefit from a contralateral HA fitting; (4) measuring bimodal benefit; and (5) how to advise patients about being a bimodal listener. A majority of respondents (83%) were unsure as to the best time to reintroduce a HA following CI activation, presumably attributable to concerns about CI acclimatization discussed previously.

Interim summary
Respondents indicated that it may be in the best interests of the patient to have both devices managed by a single centre but acknowledged the practical limitations of this model. The general view that the optimization of HA fittings following implantation is within the role of the CI audiologist appeared to suggest that what respondents reported as being their current practice is not always able to reflect what they believe to be optimal for the patient. Bimodal aiding was viewed as potentially more advantageous to the patient than wearing the CI alone, and sympathetic bimodal fitting was also viewed more favourably than devices that had not been sympathetically fit. Bimodal outcome measurements appear to be considered clinically useful, although it is unclear if and how these measurements inform HA optimization. Respondents acknowledged that further guidance on aspects of bimodal fitting is required to implement changes in routine fitting practice.

Discussion
A survey of CI audiologists across the UK characterized their reported clinical practice around bimodal aiding, identified factors that may be limiting the provision of bimodal aiding, ascertained their views on bimodal aiding, and demonstrated consistencies and inconsistencies in practice across the UK.

Changing candidacy landscape
Until relatively recently, few individuals with useful residual hearing in the contralateral ear received a CI in the UK. A large-scale UK study that collated outcomes from adults implanted between 1998 and 2000 demonstrated that most were unable to derive benefit from acoustic amplification pre-operatively (UKCISG, 2004a). Even candidates who had some measurable speech understanding using HAs (‘marginal HA users’) were receiving only minimal benefit from amplification in their better ear and had an average open-set speech discrimination score of only 13%. Respondents to the current survey estimated that approximately half of those implanted within the last five years will continue to wear a HA even after their CI is activated, suggesting that contemporary CI recipients may receive additional benefits from contralateral acoustic amplification. This estimate is compatible with the results of a recent survey of CI users, which found that 48% of respondents who had been implanted in the UK in the five years between 2010 and 2015 reported using a contralateral HA (Fielden et al., in press). It would therefore appear as if there has been an increase in the number of CI candidates who have aidable residual hearing since both the last UK-wide outcomes study and the publication of NICE guidance (NICE, 2009).
One impact of this change in who is receiving CIs in the UK is that a large proportion of recipients may no longer be monaural listeners whose outcomes are determined solely by a single implanted ear as was previously the case, but rather binaural listeners who may derive benefits from the combination of the CI and the HA. In these patients, CI audiologists have had to shift their focus away from considering an outcome solely in terms of a patient’s capacity to use their CI and towards an outcome based on binaural listening. However, this apparent change in practice has occurred in the absence of any guidance or training and is therefore likely to be based predominantly upon clinical experience. The disconnect apparent in the survey between the role of audiologists working in CI centres today and the evidence available to them with which to inform their practice may explain why the current provision of bimodal aiding appears to be inconsistent and at odds with the views of those who deliver it.

Estimates of sustained bimodal usage
While audiologists in the survey estimated that approximately half of those implanted within the last five years will wear a HA at activation, they also estimated that less than half of these patients will continue to wear their HA once they have used their implant for a further five years. This estimate of the proportion of longer-term bimodal users contrasts with previous estimates that have assumed a constant proportion of around 70% of implant recipients (Bond et al., 2009). The reasons for the estimated drop in the number of bimodal users over time are unclear, but at least five plausible explanations are apparent. First, the bimodal benefit perceived by the patient may lessen as they become more proficient at listening using the CI. Second, the amount of residual hearing may be so marginal that the natural progression of the hearing loss over time may reduce HA benefit leading to eventual non-use, perhaps because the better-hearing ear was selected for implantation. Third, the independent fitting of both devices may mean that some patients struggle to integrate the electric and acoustic signals and eventually stop using the HA. Fourth, as HAs are not typically maintained by CI centres there is a lack of cohesion between hearing services, and the bimodal patient may receive conflicting advice at each service or find it impractical to access HA maintenance services over time. Finally, it is possible that only a small proportion of UK CI users can obtain consistent and useful bimodal benefits in spite of the previous four issues, and are therefore the ones to persist with contralateral HA usage. It is impossible to know which of these, if any, could potentially contribute to poor rates of sustained HA use. More research is needed to isolate the reasons that could contribute to non-use of contralateral HAs and to provide more direct evidence for the number and nature of patients who could receive ongoing bimodal benefits.

Nature of bimodal benefit
While the majority of audiologists agreed that bimald aiding can be beneficial and encourage patients to wear a contralateral HA, the survey highlighted some uncertainty around best practice. For example, uncertainty was evident about who could benefit from bimodal aiding, when to introduce the HA after CI activation and how to fit devices sympathetically. This uncertainty may be a result of the limited available evidence for what aspects of hearing status determine the degree of bimodal benefit available to the patient. A systematic review of the effectiveness for cochlear implantation as a treatment for severe-profound deafness found that studies comparing bimodal aiding with unilateral CI or bilateral CI were poor in quality and low in number (Bond et al., 2009). To date, there is a lack of agreement in the literature as to what aspects of the HA signal delivery contribute to bimodal benefit with the possibilities including access to low frequency acoustic cues (Zhang et al., 2010), spectral modulation detection (Zhang et al., 2013), or how effectively the modalities integrate (Yoon et al., 2015). Notably, these and other studies that have demonstrated bimodal benefit have been conducted almost exclusively on patients implanted outside the UK who have greater levels of residual hearing in the non-implanted ear than are typically accessible to UK patients. Therefore, further research on UK patients is needed to ascertain whether similar benefits are possible given the current candidacy criteria. However, even if the benefits can be realized there appears to be both a lack of consistency for how to identify who may benefit from bimald aiding and how to optimize bimald devices to maximize benefit.

Influence on the choice of ear to implant
Responses to the present survey suggest that audiologists are considering the potential benefits from preserving patients’ access to residual acoustic hearing when recommending which ear to implant in at least some patients. Compatibly, a recent hypothetical decision-choice experiment suggested that clinicians may not always advise implanting the ‘optimal’ ear for CI outcomes in order to preserve residual hearing where possible (Fielden et al., in press). Given that little would be gained if residual hearing was preserved by recommending a physiologically unresponsive ear for implantation, their willingness to consider residual hearing may suggest that centres are now seeing more patients in whom both ears are receptive to
implantation; i.e. are likely to improve performance if implanted. The results may therefore suggest that audiologists are now able to be increasingly cautious about risking the loss of residual hearing in patients where the choice of ear is not strongly influenced by other factors. However, it remains unclear to what extent factors relating to residual hearing inform decision making around which ear to implant, how frequently, and in what proportion of patients. As the present results suggest that audiologists’ practice remains focused on maximizing outcome using the CI alone, it is likely that the choice of ear is still influenced primarily by factors such as the physiological responsiveness and duration of deafness of each ear, which can be used to estimate the likelihood that implanting a particular ear will improve performance compared to the best-aided condition using HAs alone (UKCISG, 2004b).

Commissioning arrangements
The disconnect between the apparent willingness of the respondents to encourage bimodal aiding and the fact that services related to bimodal aiding are reportedly rarely provided may be attributable, at least in part, to the manner in which implantation services are commissioned in the UK. The guidance from NICE which informs current commissioning arrangements was based on an assessment of the effectiveness and cost-effectiveness of cochlear implantation in the UK that compared acoustic HAs to the provision of either unilateral implantation or bilateral implantation (Bond et al., 2009). While the economic evaluation did account for the fact that a subset of patients continue to use a HA following cochlear implantation and therefore incur additional costs to the health service, the evaluation did not assume any incremental benefit arising from the provision of a well-fit acoustic HA in the non-implanted ear. The decision to not account for any bimodal benefit was based primarily on the lack of robust evidence for the impact that bimodal aiding has on the overall health and wellbeing of patients. In the absence of such evidence in UK patients and therefore evidence for the cost-effectiveness of bimodal aiding, it is unlikely that funding arrangements will change to include maintenance provision of two devices in those patients who may benefit from their use.

Practical considerations
The survey highlighted practical problems that would arise if a single service were to maintain both devices with respondents identifying issues related to staff time and funding as potential limiting factors. While an integrated model of service provision would likely provide a smoother service for the patient, create a more cohesive care pathway, and facilitate the sympathetic optimization of the two devices, it may also be less convenient for the patient who may have to travel many miles to reach their nearest CI centre for minor adjustments to the HA or to obtain replacement parts. A more practical arrangement could be for the CI centre to take responsibility only for the fitting and reprogramming of HAs, while routine maintenance and spare parts continued to be provided by local audiology departments. A more radical approach would be for certain aspects of CI care to be undertaken by local audiology departments, perhaps with remote assistance from the CI centre. However, this approach would currently not meet the standard for quality of care as specified in the BCIG quality standards report (NICE, 2007). This option would therefore require considerable investment to ensure that remote standards of care were achieved. Another option that is already being explored by CI centres nationally is the adoption of outreach clinics, which could be extended to support bimodal fittings.

Given the increasing numbers of CI users requiring ongoing maintenance and the numbers of patients who could now be aided bimodally, changes to the current model of service provision would appear to be inevitable. Audiologists generally appear to be willing to consider changes in their practice to enhance the provision of bimodal aiding, but the lack of evidence with which to inform their practice and practical issues related to time and funding severely limit the nature and scope of any changes that could be made at the present time.

Recommendations for future research
This survey has demonstrated that UK audiologists are willing to consider changing their practice relating to bimodal aiding but have identified a need for guidance on best practice regarding: (a) the fitting and evaluation of HAs during candidacy assessment; (b) identifying who is likely to benefit from bimodal aiding; (c) providing advice on HA use at CI switch-on; (d) optimizing bimodal aiding (including sympathetic bimodal fitting); and (e) using bimodal outcome measurement to both inform fitting and monitor changes in performance. The creation of guidance on these topics is currently hindered by a lack of evidence for the size and nature of bimodal benefits that are available to UK CI users and evidence for whether the methodologies that have been proposed for optimizing the fitting of bimodal devices are applicable to clinical practice in the UK.

At the very least, the development of new guidance would require: (a) an up-to-date systematic review of the evidence for the effectiveness of bimodal aiding that includes patients with limited residual hearing similar to that of UK patients; (b) evidence that the provision of bimodal aiding is a cost-effective use of
limited NHS resources; (c) evidence that existing bimodal fitting and assessment methods are appropriate for use UK patients; and (d) a consensus among clinicians on those aspects of bimodal fitting that are feasible to implement and of benefit to patients. While the current survey has identified some aspects of practice and views that appear to be held consistently across UK CI centres, any consensus exercise to inform guidance would ideally be formed using an established methodology such as a Delphi process (Dalkey, 1969) and involve the broad range of healthcare professionals that deliver the current care pathway. Further research should also engage with UK CI recipients whose experience can contribute to a better understanding of the benefits and disadvantages of bimodal aiding, and why patients choose to use or not to use a contralateral HA.

Ultimately, an evaluation of the benefits that bimodal aiding provides to UK patients should be based on well-designed clinical controlled trials. It is only when such robust evidence is available that current clinical commissioning arrangements are likely to be amended to both recommend and fund bimodal aiding in the UK.

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Conflicts of interest The authors declare no conflicts of interest.

Ethics approval The authors used the decision making tool provided by the UK Health Research Authority to determine whether ethical approval was required (http://hra-decisiontools.org.uk/ethics/). As this study was not research (but a survey of current clinical practice) and only involved contacting healthcare professionals through their relevant a professional organization (the British Cochlear Implant Group), the tool indicated that ethical approval was not required.

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