Predicting speech perception outcomes following cochlear implantation in adults with unilateral deafness or highly-asymmetric hearing loss

Pádraig T. Kitterick[1,2] and Laura Lucas[1,2]

[1] National Institute for Health Research Nottingham Hearing Biomedical Research Unit, 113 The Ropewalk, Nottingham NG1 5DU

[2] Otology and Hearing Group, Division of Clinical Neuroscience, School of Medicine, University of Nottingham NG7 2RD

Contact author: Pádraig Kitterick, padraig.kitterick@nottingham.ac.uk

Acknowledgements

This work was supported by infrastructure funding from the National Institute for Health Research (NIHR). The views expressed are those of the author(s) and not necessarily those of the NHS, the NIHR or the Department of Health.

PTK is co-ordinating a trial of cochlear implantation in adults with acquired unilateral deafness that is part-funded by Cochlear Europe Ltd.

Keywords: unilateral deafness, single-sided deafness, asymmetric hearing loss, cochlear implantation, binaural hearing, speech perception, duration of deafness.

Word count (including references and abstract): 1842

Total number of figures and tables: 2

Abstract

Unilateral deafness and highly-asymmetric hearing loss can impair listening abilities in everyday situations, create substantial audiological handicap, and reduce overall quality of life. Preliminary evidence from early-phase studies in adults suggests that cochlear implantation may be effective in reversing some of these detrimental effects. Patient-level data from existing studies was re-analysed to explore potential factors that may be predictive of improved speech perception scores following implantation. The results suggest that duration of deafness in the severe-to-profoundly deaf ear and hearing sensitivity in the better (non-implanted) ear may be relevant when seeking to identify those candidates who are likely to obtain benefit following cochlear implantation.

Introduction

Access to hearing in one ear only can create difficulties with listening in most everyday environments (Dwyer et al., 2015). This absence of auditory input leads to difficulties with understanding speech when the talker of interest is on the impaired side and also in determining the location of sounds. The cumulative effects of the impairments to hearing functions and the associated impact on everyday life can lead to strong negative feelings including embarrassment and helplessness (Giolas & Wark, 1967).

Emerging evidence from early-phase studies suggests that cochlear implantation may be an effective way to improve listening skills impaired by unilateral deafness (Blasco & Redleaf, 2014; van Zon et al., 2015) and to alleviate the associated burden (Kitterick et al., 2015). However, the evidence for implantation in unilaterally-deaf patients is limited to a few observational studies and it is as yet unclear what factors may determine whether a patient is likely to receive benefit or not. A meta-analysis which pools the small samples of unilaterally-deaf patients that have been assessed in existing studies could provide sufficient statistical power to identify potential factors that could subsequently be evaluated prospectively in future studies.

The current study re-examined the existing published evidence for the capacity of cochlear implantation to improve speech perception in noise in order to identify whether factors known to predict outcomes following implantation in the profoundly deaf may also be relevant when determining candidacy in the unilaterally deafened. It was hypothesised that when the spatial configuration of speech in noise creates a more favourable signal-to-noise ratio (SNR) at the severe-to-profoundly deaf ear, the performance of unilaterally-implanted listeners would depend on the duration of deafness prior to implantation as auditory deprivation reduces the receptivity of an implanted ear to electrical stimulation (Tyler & Summerfield, 1996). Conversely, when the SNR is made more favourable at the better ear then performance would be expected vary as a function of the level of residual hearing in that ear, as indexed by its pure-tone average threshold.

Methods

Study selection

Studies were identified from existing systematic reviews that assessed the evidence for cochlear implantation in adults with unilateral deafness or highly-asymmetric hearing loss (Blasco & Redleaf, 2014; Kitterick et al., 2015; van Zon et al, 2015). These reviews were identified through title and abstract searches of the Medline, EMBASE, PubMed, and Cochrane Library databases. The search strategy was: (unilateral OR asymmetric OR single-sided) AND (deafness OR hearing loss) AND systematic review. To be included in the current re-analysis, studies identified through the systematic reviews had to report patient-level data for adult patients on duration of deafness in the severe-to-profoundly deaf ear, pure-tone average audiometric thresholds in the better ear (averaged across 0.5, 1, 2 and 4 kHz), and outcomes on measures of speech perception in noise (see following section).

Extraction of outcome data

Previous studies have assessed the perception of sentences in noise in three categories of listening condition defined by the relative difference between the signal-to-noise ratio (SNR) at the impaired/implanted ear (IE) and the non-implanted ear (NE): (1) when the SNR at the two ears are similar (IE=NE); (2) when the SNR is more favourable at the impaired ear (IE>NE); and (3) when the SNR is more favourable at the non-implanted ear (IE<NE). Data

on these three listening conditions were extracted independently by the two authors and disagreements were resolved by consensus.

Statistical analysis

Although outcome data was extracted for a common set of listening conditions, the methodology used to measure performance differed across studies; e.g. as the proportion of key words reported correctly or as a speech reception threshold. The approach of rendering different measures of the same outcome comparable by expressing the pre-post change as an effect size was not possible as studies did not report estimates of variability at the individual level. Instead, each patient's outcome in each listening condition was coded as a binary variable whose value was set to 1 if the patient's score improved numerically following implantation and 0 if it did not.

The resulting binary variable for each of the three listening conditions was subjected to logistic regression. Any heterogeneity in the inclusion criteria and methodologies used in the selected studies would likely result in patients being more similar within than across studies. A Generalised Estimating Equations approach to regression accounted for this clustering of patients within studies. The model predicted the probability of an improvement in speech perception scores following implantation based on the duration of deafness of the severe-to-profoundly deaf ear and the four-frequency pure-tone average of the better (non-implanted) ear.

Results

Table 1 lists the characteristics of 34 adults for whom relevant data could be extracted from four published reports. The mean duration of deafness in the severe-to-profoundly deaf ear was 7 years but varied considerably across the patients (range 0.3-40 years). A small number of patients experienced extended periods (>20 years) of auditory deprivation prior to implantation. The mean pure-tone average threshold in the better ear was 16.3 dB HL and all patients had four-frequency average thresholds within the normal-to-mild range (3-39 dB HL).

Table 1 about here

The results of the logistic regression model are listed in Table 2. The analysis indicated that those with a shorter duration of deafness in the severe-to-profoundly deaf ear prior to implantation were more likely to improve in the listening condition that created the least-favourable SNR at the implanted ear (IE<NE), with the odds decreasing by 0.03 (95% confidence interval 0.01 to 0.06) with each additional year of auditory deprivation. Conversely, those with lower pure-tone average thresholds in the better ear were more likely to improve in the listening condition that created the least-favourable SNR at that ear (IE>NE); each additional 1-dB degradation in hearing level reduced the odds by 0.14 (95% confidence interval 0.04 to 0.25). No effect of either factor was observed when the spatial configuration of speech and noise resulted in similar SNRs at the two ears.

Table 2 about here

Discussion

The most consistent benefit to speech perception following implantation in the unilaterally deaf arises when the SNR is more favourable at the implanted ear; e.g. when speech is directed towards the implanted ear and noise towards the non-implanted ear (Blasco & Redleaf, 2014; van Zon et al., 2015). In this listening situation, use of the implant allows the patient to access a copy of the speech signal that is less degraded than that which is accessible using their better ear alone. It is therefore surprising that the influence of duration of deafness in the severe-to-profoundly deaf ear was evident in the condition that created the *least*-favourable SNR at the implanted ear (IE<NE). This finding could suggest that the length of auditory deprivation may affect a patient's capacity to exploit the subtle benefits of binaural squelch rather than to engage in better-ear listening.

It is also possible that the observed effect of duration of deafness was driven by the small number of patients who had been deaf for several decades. To test this idea, the skewed duration of deafness data was treated as a categorical rather than a continuous variable and recoded based on whether a duration was less than or greater than 20 years. The adjusted regression model identified those with longer durations of deafness as being far less likely to show an improvement following implantation (Odds ratio 0.38, 95%CI 0.17 to 0.83). This finding is compatible with an international consensus statement on candidacy for implantation in the unilaterally deaf, which recommended that more caution should be exercised when determining candidacy in patients with extended periods of auditory deprivation (Vincent et al. 2015).

While the current analysis gained statistical power by pooling data across several small studies with similar inclusion criteria, the results should be interpreted with caution. The underlying studies are early-phase uncontrolled studies and the resulting data may have been influenced by selection and observation bias. However, the current approach demonstrates the potential benefits that can be gained from collecting data using consistent methodologies and the inclusion of patient-level data in study reports. In such a relatively small population, meta-analytic approaches could play an important role in identifying factors important for candidacy.

Conclusion

Evidence from early-phase studies suggests that duration of deafness in the severe-to-profoundly deaf ear and hearing sensitivity in the better ear of unilaterally-deaf patients may be relevant when seeking to identify those candidates who are likely to obtain benefit to speech understanding in noise following cochlear implantation.

References

Arndt, S., Aschendorff, A., Laszig, R., Beck, R., Schild, C., Kroeger, S., Ihorst, G. and Wesarg, T., (2011). Comparison of pseudobinaural hearing to real binaural hearing rehabilitation after cochlear implantation in patients with unilateral deafness and tinnitus. Otology & Neurotology, 32(1), pp.39-47.

Blasco, M.A. and Redleaf, M.I., (2014). Cochlear implantation in unilateral sudden deafness improves tinnitus and speech comprehension: meta-analysis and systematic review. Otology & Neurotology, 35(8), pp.1426-1432.

Dwyer, N.Y., Firszt, J.B. and Reeder, R.M., (2013). Effects of unilateral input and mode of hearing in the better ear: self-reported performance using the speech, spatial and qualities of hearing scale. Ear and hearing, 35(1), pp.126-136.

Firszt, J.B., Holden, L.K., Reeder, R.M., Cowdrey, L. and King, S., (2012). Cochlear implantation in adults with asymmetric hearing loss. Ear and hearing, 33(4), p.521.

Giolas, T.G. and Wark, D.J., (1967). Communication problems associated with unilateral hearing loss. Journal of Speech and Hearing Disorders, 32(4), pp.336-343.

Kitterick, P.T., Lucas, L. and Smith, S.N., (2015). Improving Health-Related Quality of Life in Single-Sided Deafness: A Systematic Review and Meta-Analysis. Audiology and Neurotology, 20(Suppl. 1), pp.79-86.

Távora-Vieira, D., Marino, R., Krishnaswamy, J., Kuthbutheen, J. and Rajan, G.P., (2013). Cochlear implantation for unilateral deafness with and without tinnitus: a case series. The Laryngoscope, 123(5), pp.1251-1255.

Tyler, R. S., Summerfield, A. Q., (1996). Cochlear implantation: relationships with research on auditory deprivation and acclimatization. Ear and Hearing, 17(3 Suppl), 38S-50S.

van Zon, A., Peters, J.P., Stegeman, I., Smit, A.L. and Grolman, W., (2015). Cochlear implantation for patients with single-sided deafness or asymmetrical hearing loss: a systematic review of the evidence. Otology & Neurotology, 36(2), pp.209-219.

Vermeire, K. and Van de Heyning, P., (2009). Binaural hearing after cochlear implantation in subjects with unilateral sensorineural deafness and tinnitus. Audiology and Neurotology, 14(3), pp.163-171.

Vincent, C., Arndt, S., Firszt, J.B., Fraysse, B., Kitterick, P.T., Papsin, B.C., Snik, A., Van de Heyning, P., Deguine, O. and Marx, M., (2015). Identification and Evaluation of Cochlear Implant Candidates with Asymmetrical Hearing Loss. Audiology and Neurotology, 20(Suppl. 1), pp.87-89.

Legends

Table 1. Individual patient characteristics extracted from four published studies identified from existing systematic reviews. 4FPTA: Four-frequency pure-tone average audiometric threshold.

Table 2. Odds ratios associated with showing an improvement in speech perception score following implantation and their confidence intervals for each predictor included in the regression model of each listening condition. Confidence intervals that do not include 1.0 indicate a statistically significant association between the predictor and an improved speech perception score following implantation (** $p<.01$). IE: impaired/implanted ear SNR; NE: non-implanted ear SNR. 4FPTA: Four-frequency pure-tone average audiometric threshold.

ID	Study	Duration of deafness (years)	Better-ear 4FPTA (dB HL)	ID	Study	Duration of deafness (years)	Better-ear 4FPTA (dB HL)
1	Arndt et al. 2010	3.6	13	18	Tavora et al. 2013	1.0	18
2		2.6	18	19		0.6	13
3		0.3	8	20		39	3
4		2.8	8	21	Firszt et al. 2012	0.8	21
5		0.5	9	22		4.5	28
6		0.8	9	23		2.5	23
7		0.9	8	24	Vermiere et al. 2009	8.5	28
8		9.2	7	25		2.5	15
9		0.8	16	26		13.5	10
10		0.8	30	27		2	10
11		0.3	16	28		5.5	25
12	Tavora et al. 2013	3.0	10	29		6.5	11
13		2.0	18	30		2.5	15
14		40	13	31		8	11
15		0.6	25	32		10	18
16		20	18	33		3	13
17		35	28	34		1.5	39

Table 1

	Duration of deafness (years)	**Better-ear 4FPTA (dB HL)**
IE<NE	0.97 (0.94 to 0.99)**	1.05 (0.97 to 1.14)
IE=NE	1.00 (0.98 to 1.03)	1.04 (0.93 to 1.17)
IE>NE	1.07 (0.98 to 1.17)	0.88 (0.80 to 0.96)**

Table 2