The effect of side of implantation on unilateral cochlear implant performance in patients with prelingual and postlingual sensorineural hearing loss: A systematic review

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Objective: Cerebral lateralisation of language processing leads to a right ear advantage in normal hearing subjects. The aim of this study was to present a systematic overview of the effect of implantation side on postoperative cochlear implant performance in patients with symmetrical severe to profound sensorineural hearing loss.

Data sources: PubMed, Embase and The Cochrane Library databases.

Research methods: Databases were searched from database inception up to 9 January 2017 for cochlear implant and side and all synonyms. Title, abstract and full-text of retrieved articles were screened for eligibility. Then, directness of evidence and risk of bias were assessed. For the included articles, study characteristics and outcome data (hearing and language development) were extracted.

Results: 2541 unique articles were screened, of which twenty were eligible for critical appraisal. No randomised controlled trials were identified. Twelve studies with a high directness of evidence remained for data extraction. Four of six studies including children with pre-lingual sensorineural hearing loss and four of seven studies investigating adults with postlingual sensorineural hearing loss found a right ear advantage in at least one outcome measurement related to cochlear implant performance.

Conclusion: The available evidence on the effect of side of implantation is of low quality, as study populations and outcome measures are heterogeneous. The majority of studies reveals evidence for a right ear advantage in prelingually deafened children as well as postlingually deafened adults. In view of the present evidence and as no left ear advantage was identified, we cautiously advise implanting the cochlear implant in the right ear when other prognostic factors do not favour the left ear and sensorineural hearing loss is symmetrical.

INTRODUCTION

Since the introduction of cochlear implants (CIs), millions of patients have been implanted, of which the vast majority unilaterally. The selection of ear is based on various functional and anatomical factors, of which durations of deafness and anatomical variations are the most important ones.1 When sensorineural hearing loss is of equal duration, symmetrical and there are no anatomical constraints, it is argued that a CI should be implanted ipsilateral to a patient’s dominant hand for easy device use.2 The side of implantation could possibly also influence postoperative CI performance.3 This hypothesis is based on the combination of two assumptions.
The first assumption is that one hemisphere in the brain is of greater influence on brain functions such as speech and language processing compared to the contralateral hemisphere. For speech perception and speech production, left hemisphere dominance is seen in 95-98% of right-handed and in 70-80% of left-handed normal hearing (NH) subjects. In contrast, for prosodic language functions such as intonation and accentuation, right hemisphere dominance is seen in the majority of these subjects. Overall, the majority of people have a dominant left hemisphere for speech and language processing.

The second assumption is that although the auditory cortex receives auditory input from both ears, it is most strongly stimulated by the contralateral ear. Several functional magnetic resonance imaging studies have revealed that auditory input in one ear predominantly projects to the contralateral superior olivary complex and from there to the contralateral auditory cortex. For example, after presentation of monosyllables in a study by Suzuki et al, 2.5 times more voxels were activated in the contralateral auditory cortex compared to the ipsilateral auditory cortex of the stimulated ear.

The combination of the assumptions described above results in a phenomenon called "the right ear advantage" (REA), meaning that in the majority of NH subjects, the right ear is most important for the perception and production of speech. Subsequent to a difference in hemispheric lateralisation between right-handed and left-handed people, there is a difference in the proportion of people that exhibit a REA between right-handed (79%) and left-handed people (68%).

Extensive research in NH subjects has demonstrated that the REA can be influenced by both bottom-up and top-down manipulations. For example, in dichotic listening tests, the REA is augmented when the signal intensity in the right ear increases. Conversely, when the signal intensity in the left ear increases, the REA shifts to a left ear advantage. Functional magnetic resonance imaging has demonstrated that the cerebral activation patterns also differ in the "right ear focus" and "left ear focus" situation, indicating the variance in processing of the auditory stimuli. Furthermore, EEG recording of event-related potentials (ERPs) has shown that the ERP latency from the right ear is shorter in the right ear focus situation, while it is longer in the left ear focus situation. These examples demonstrate that the auditory processing and thus the perceived REA is actually affected by top-down manipulations. This led us to question whether hearing loss may affect the REA as well.

Although bilaterally deafened subjects benefit from bilateral CIs more than from a single CI with regard to speech perception in noise and localisation of sounds, currently the majority of deaf subjects is still implanted unilaterally mainly due to reimbursement issues. For that reason, it is valuable to know which ear should be implanted when duration of deafness and other factors do not differ between the left and right ear. In that respect, it is of interest to investigate whether a REA exists in bilaterally deafened, unilaterally implanted CI users. The aim of this systematic review is to assess the current literature on the effect of side of implantation on postoperative CI performance, in prelingually deafened and postlingually deafened subjects with symmetrical severe to profound sensorineural hearing loss (SNHL).

2 METHODS

2.1 Search and selection

We performed a systematic search in PubMed, Embase and the Cochrane databases on 9 January 2017. The search syntax included relevant synonyms for the search terms 'cochlear implant' and 'side' (please view Table 1 for the search syntax). After removal of duplicates, title and abstract screening was performed independently by two authors (V.J.C.K. and T.C.D.) according to predetermined inclusion and exclusion criteria. Eligible full-text articles were retrieved through the databases and by emailing authors. Subsequently, full texts of eligible articles were screened independently (V.J.C.K and T.C.D.). We searched Web of Science for additional relevant articles. Discordances regarding inclusion were resolved by discussion and consensus. The PRISMA statement was used as a guideline for set-up and writing of this systematic review.
2.2 Study eligibility criteria

Studies reporting original data on the effect of side of cochlear implantation on postoperative hearing, speech and language outcomes were included. We were interested in unilaterally implanted patients; therefore, studies with (some) bilaterally implanted patients were excluded, when no subanalysis for unilateral patients was presented. The outcome measures for cochlear implant performance were clinically administered hearing, speech and language tests.

2.3 Quality assessment

As shown in Table 2, we appraised the selected studies independently for directness of evidence (DoE) and risk of bias (RoB), using predefined criteria. DoE was scored by evaluation of population, intervention and outcome. Items were scored as satisfactory, partly satisfactory or unsatisfactory.

We assessed RoB by the use of several criteria. First, we examined the design of a study and, if prospective, whether blinding and randomization were performed. Second, we assessed the standardisation of outcome measurements. Standardisation was assessed as satisfactory when a validated test was used. Third, we assessed the handling of missing data and loss to follow-up. Fourth, we assessed whether follow-up was at set times or the timing differed per patient. Finally, we assessed handling of possible confounders. Disagreement was resolved by discussion and consensus.

2.4 Data extraction and analysis

Two researchers (V.J.C.K. and T.C.D.) independently extracted descriptive data regarding the onset of hearing loss (prelingually or postlingually), side of implantation and hearing, speech and language outcomes from the selected studies.

3 RESULTS

3.1 Search strategy and study selection

As shown in Figure 1, our search identified a total of 3551 articles, of which 2541 were unique. After screening on title and abstract, 30 articles were left for full-text screening. Reference checking yielded five additional possibly relevant articles provided that data could be obtained from the corresponding authors. Two references were published conference abstracts, one was a letter to the editor and twelve articles were not eligible because of a non-corresponding population, intervention or outcome. Consequently, twenty articles were eligible for critical appraisal.
| Author (y)    | Design | Sample size | Patients | Therapy | Outcome | Data extractability | Selection bias | Randomization | Blinding | Standardization of outcome | Missing data | Lost to follow up | Follow-up | Confounding |
|--------------|--------|-------------|----------|---------|---------|---------------------|----------------|---------------|----------|--------------------------|--------------|------------------|-----------|-------------|
| Blamey 2015  | RC     | 1572        | ●        | ●       | ●       | ●                   | ●               | ○             | ○        | ?                        | ●            | ○                | ●         |             |
| Budenz 2011  | RC     | 108         | ●        | ●       | ●       | ●                   | ●               | ○             | ○        | ●                        | ●            | ●                | ○         |             |
| Chilosi 2014 | CC     | 20          | ●        | ●       | ●       | ○                   | ○               | ○             | ○        | ○                        | ○            | ○                | ●         |             |
| Deguine 1995 | RC     | 76          | ●        | ●       | ●       | ○                   | ○               | ○             | ○        | ?                        | ○            | ○                | ○         |             |
| Filipsem 2008| CSS    | 15          | ●        | ●       | ●       | ●                   | ●               | ○             | ○        | ○                        | ○            | ●                | ○         |             |
| Friedland 2003| RC    | 58          | ●        | ●       | ●       | ●                   | ●               | ●             | ●        | ○                        | ○            | ○                | ●         |             |
| Henkin 2008  | RC     | 71          | ●        | ●       | ●       | ●                   | ●               | ●             | ●        | ○                        | ○            | ○                | ●         |             |
| Holden 2012  | PC     | 114         | ●        | ●       | ●       | ○                   | ●               | ○             | ○        | ?                        | ●            | ○                | ●         |             |
| Kamal 2014   | RC     | 68          | ●        | ●       | ●       | ●                   | ●               | ○             | ○        | ?                        | □            | ●                | ●         |             |
| Kraaijenga 2015| RC   | 428         | ●        | ●       | ●       | ●                   | ●               | □             | ●        | ○                        | ○            | ○                | ○         |             |
| Mohammed & Sarwat 2014| CSS | 50 | ●        | ●       | ●       | ○                   | ○               | ○             | ○        | ?                        | NA          | ○                | ○         |             |
| Morris 2006  | RC     | 101         | ●        | ●       | ●       | ●                   | ●               | ○             | ○        | ●                        | ●            | ○                | ○         |             |
| Mosnier 2014 | PC     | 94          | ●        | ●       | ●       | ●                   | ○               | ○             | ○        | ?                        | □            | ●                | ●         |             |
| Muzaffar & Meyer 2012 | RC | 84 | ●        | ●       | ●       | ●                   | ●               | ○             | ○        | ●                        | ●            | ●                | ○         |             |
| Roberts 2013 | RC     | 113         | ●        | ●       | ●       | ●                   | ●               | ○             | ○        | ○                        | ○            | ●                | ●         |             |
| Roman 2004   | CCS    | 7           | ●        | ●       | ●       | ●                   | ●               | ○             | ○        | ●                        | NA          | ○                | ○         |             |
| Sharpe 2016  | RC     | 96          | ●        | ●       | ●       | ●                   | ●               | ○             | ○        | ●                        | ●            | ○                | ○         |             |
| Surmeliglu 2014 | RC | 63 | ●        | ●       | ●       | ●                   | ●               | ○             | ○        | ?                        | ?            | ●                | ○         |             |
| Wang 2011    | CSS    | 177         | ●        | ●       | ●       | ●                   | ●               | ○             | ○        | ?                        | NA          | ○                | ○         |             |
| Wu 2008      | CSS    | 60          | ●        | ●       | ●       | ●                   | ○               | ○             | ○        | ●                        | NA          | ●                | ○         |             |

**Patients**
● Patients with bilateral severe to profound SNHL | ○ asymmetrical SNHL

**Therapy**
● Unilateral cochlear implantation | ○ Bilateral and unilateral cochlear implantation | ● Bilateral cochlear implantation

**Outcome**
● Speech perception or speech production test or questionnaire | ○ other tests

**Data extractability**
● Extractable | ○ Extractable from figure | ○ Not extractable

**Selection bias**
● No selection bias | ○ selective inclusion of non-missing data in retrospective cohort | ○ Susceptible to bias | ? Not reported

**Blinding personnel**
● Blinded | ○ No blinding or not mentioned

**Standardization of outcome**
● Pre-defined externally validated test | ○ No pre-defined externally validated test

**Missing data**
● <10% of missing data or imputed | ○ 10-20% missing data | ○ >20% missing data | ? not reported or unclear

**Lost to follow-up**
● No lost to follow-up | ○ lost to follow-up, well described | ○ lost to follow-up, not described | NA in cross-sectional studies | ? Unclear

**Follow-up**
● At set times measures | ○ different follow-up moments

**Confounding**
● Corrected for or no confounding | ○ confounding present and not corrected for

RC, retrospective cohort; PC, prospective cohort; CSS, cross-sectional study; CC, case control study; NA, not applicable.
3.2 Assessing quality of studies

The critical appraisal is presented in Table 2. No randomised controlled trials (RCTs) were included in the critical appraisal. Two studies were prospective cohort studies,18,19 twelve were retrospective cohort studies,1,2,20-29 five were cross-sectional studies3,30-33 and one was a case-control study.34

Two studies included unilaterally and bilaterally implanted patients.20,33 After contacting the corresponding authors, outcome per side was not extractable in five studies.18,22,23,32,33 One study investigated electro-physiologically measured syllable discrimination which did not correspond with our predefined inclusion of outcome measures.3 All of the above resulted in a high DoE in thirteen studies1,2,19,21,24-31,34 and a low DoE in seven studies.3,18,20,22,23,32,33

Blinding and randomisation were not performed in any of the studies as no RCTs were identified. Selection of study population was unclear or susceptible to bias in eleven studies.2,3,18,21,23,25-28,30,31,34 Nine studies had more than 20% missing data, or missing data was unclear,18-20,22,24,25,29,31,32 in only seven studies, patients were equally followed-up at time of testing.1,19,21,25,26,28,29 All of the above resulted in a low RoB in two studies,1,21 moderate RoB in fourteen studies,18-20,23,25-30,33,34 and a high RoB in four studies.3,22,31,32 One study was described twice, once in a scientific poster26 and later on in an article,78 consequently, the poster was excluded from this review.

Finally, twelve studies of which eleven with a high DoE and low or moderate RoB and one study with a high RoB remained for data extraction.1,2,19,21,24-25,27-31,34

3.3 Data extraction

We were unable to pool data, because there was large clinical heterogeneity among these studies and measures of uncertainty were often not reported. Therefore, we provided a descriptive analysis.

3.4 Study characteristics

Most of the studies were retrospective cohort studies, one prospective cohort study,19 two cross-sectional studies30,31 and one case-control study.34 Six studies analysed children with prelingual SNHL24,25,29-31,34 Eight studies examined the effect of side of implantation in adults with postlingual SNHL.1,2,19,21,25,27,28,31 Two studies reported data on adults with prelingual SNHL.1,31 One study also included some adolescent implantees with postlingual SNHL.31 The majority of studies measured speech perception1,2,19,21,24,25,27,29 whereas three studies measured speech production30,31,34 with various tests. The study populations varied from 2034 to 428 patients.1

3.5 Study outcome: REA

3.5.1 Children

Table 3 contains descriptions of outcome measures used in the included studies. Of the 6 studies investigating the effect of side of implantation in children,24,25,29,31,34 five included children with prelingual SNHL, whereas Flipsen et al included children with
prelingual and postlingual SNHL. As shown in Table 4, three of five studies describing prelingual children with SNHL showed a significant REA for speech perception or speech production.24,25,31 Besides these studies, Flipsen et al found a significant benefit in the right-ear-implanted children regarding phoneme intelligibility and accuracy, but not regarding conversational speech perception.30 Two studies, Chilosi et al and Surmelioglu et al did not find a REA.29,34

### 3.5.2 Adults

As shown in Table 5, of the eight studies investigating the REA in adults with postlingual SNHL, four studies reported a significant REA for speech perception19,21,25,28 and one for speech production,31 while 3 other studies did not for speech perception.1,2,27 In adults with prelingual SNHL, Kraaijenga et al found no significant difference in speech perception between left and right implantees.1 Budenz et al showed that right ear implanted adults performed better on CNC words and phonemes, while the City University of New York tests for speech perception in quiet and noise did not differ significantly.21 Similarly, Kamal et al observed a significant difference favouring the right CI in one of the three tests used.25 Finally, Sharpe observed a significant REA for hearing in noise test scores after standardising the scores, yet not for the CVC word and phoneme scores.28

### 3.6 Handedness

Two studies performed a subanalysis on handedness. In concordance with their overall results, Morris et al found no difference between left ear and right ear implantees in a subgroup of right-handed patients.2 Henkin et al24 who found a significant REA in the whole patient group, also performed a subanalysis on the right-handed patients and found that the significantly better performance of right-implanted children compared to left-implanted children was preserved in their right-handed patients (words: $F[1,58] = 9.24$, $P = .003$; phonemes: $F[1,58] = 8.32$, $P = .005$). In addition, they performed a multivariate analysis in all patients and found no effect of dominance (eg compatibility between dominant hand and side of CI: left-handed with left CI vs. right-handed with right CI) on speech perception performance (words, $P = .84$; phonemes, $P = .65$).24

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**TABLE 3 Legend of administered tests**

| Outcome measure                  | Range    | Test content                                                                 |
|----------------------------------|----------|-----------------------------------------------------------------------------|
| **Speech perception**            |          |                                                                             |
| CVC/CNC1,25,27,28                | 0%-100%  | Consonant-vowel/noun-consonant speech perception. Scores can be calculated for the whole word or per phoneme. |
| CUNY1,20                         | 0%-100%  | City University of New York speech perception test. This test can be administered in quiet and in noise. |
| HINT1,28                         | 0%-100%  | Hearing in Noise speech perception test.                                     |
| 4 Choice Spondee24               | 0%-100%  | Closed-set spondee recognition test                                          |
| High context sentence24          | 0%-100%  | High context sentence perception test: closed set with open end             |
| AB monosyllabic word23           | 0%-100%  | Arthur Boothroyd monosyllabic word perception test; prerecorded Hebrew version |
| AB phonemes23                    | 0%-100%  | Arthur Boothroyd phoneme perception test; prerecorded Hebrew version         |
| Monosyllabic words24             | 0%-100%  | Open-set monosyllabic identification test: within vocabulary of 3-yr old child |
| Minimal pairs24                  | 0%-100%  | Closed-set speech perception test with 50% chance correct                    |
| WIPI24                           | 0%-100%  | Word intelligibility by picture identification: closed-set                   |
| LIP29                            | 0%-16    | Listening progress profile identifies 3 different skills: response, discrimination, and identification. |
| LittEars29                       | 0-35     | The LittEARS® Auditory Questionnaire [Coninx 2009]                           |
| **Speech production**            |          |                                                                             |
| MAIS29                           | 0-36     | Meaningful auditory integration scale [Zimmerman-Phillips]                   |
| CSIM30                           | 0%-100%  | Children’s speech intelligibility measure                                  |
| BIT30                            | 0%-100%  | Beginners’ intelligibility test                                             |
| GFTA-2                           | Std for age | Goldman-Fristoe test of articulation - second edition. Mean (SD): – 100 (15) |
| PCC30                            | 0%-100%  | Percentage consonants correct                                               |
| PVC30                            | 0%-100%  | Percentage vowels correct                                                   |
| Arabic speech intelligibility test31 | 0%-100% | Children’s speech intelligibility test using pictures resulting in an overall speech intelligibility score (%) |
| **Auditory performance**         |          |                                                                             |
| Composite test38                 | 4-8      | Composite test composed of one-word picture vocabulary test, peabody picture vocabulary test, test of comprehension of grammar for children, language production elicited by ITCD paradigm and sentence repetition task |

Stnd, standardised.
**DISCUSSION**

As the lateralisation in the NH brain is already so complex and impressionable, this raises the question if, and how, the phenomenon "REA" in NH subjects can be translated to the situation of patients with SNHL and a CI. There is evidence that hearing loss affects the REA differently dependent on whether the onset of hearing loss was prelingual or postlingual. Early auditory deprivation in children has shown to cause an atypical organisation of the auditory nervous system.35,36 Through functional Transcranial Doppler ultrasonography, hemisphere laterisation in unilaterally implanted children with symmetrical SNHL (n = 20) was studied.27 Thirteen children had a right CI, of which the majority (77%) demonstrated left hemisphere dominance. Seven children had a left CI. Interestingly, 3 of the 4 left-implanted children with age at implantation below 3 years, showed right hemisphere dominance for speech perception. The remaining child had an inconclusive result. In contrast, the two later left ear implanted children (>8 years) developed ipsilateral left hemisphere dominance. The authors suggest that unilateral reaferentation of the left ear can induce reorganisation of language functions in the right hemisphere when it takes place in a critical period early in life when the brain is (still) plastic.37 Plasticity of the brain is maximal in the first 3.5 years of life.35,36 Consequently, with a right ear implant or later implantation of the left ear, the established patterns of left hemisphere dominance are preserved. Similar results were seen in a study by Henkin et al in which speech perception and speech processing patterns were compared between right ear and left ear implanted children. Although speech perception was equal between both groups, speech processing patterns assessed with low-resolution electromagnetic tomography were similar to NH subjects for the right ear implanted children (bilateral temporal lobe) whereas enhanced ipsilateral temporal lobe activation was seen in the left ear...
The left ear implanted children’s brains adapted to unilateral auditory input in the left ear and consequently reafferentation took place to ensure sufficient input to the dominant left hemisphere. Such altered patterns of input (increased ipsilateral and decreased contralateral processing of speech compared to NH subjects) have been demonstrated in adults with unilateral SNHL as well. In children with unilateral SNHL, worse verbal and non-verbal performances with right-sided, unilateral SNHL compared to left-sided, unilateral SNHL have been described, indicating that it is the right ear that adds the greatest contribution to speech perception.

In this systematic review, we provide an overview of studies that investigated the influence of side of implantation on hearing, speech and language outcomes after unilateral cochlear implantation. Four

| Study (y) | Test | Study population | Sample size | Score post implantation |
|-----------|------|------------------|-------------|-------------------------|
| Morris (2006)¹ | HINT sentence (%) | 38 | 80 | 70 | .57 |
| | CUNY quiet (%) | | 90 | 79 | .82 |
| | CUNY noise (%) | | 85 | 73 | .80 |
| | CNC word (%) | | 49 | 45 | .60 |
| | CNC phoneme (%) | | 66 | 57 | .45 |
| | Sub analysis right-handed patients | | 24 | 43 | .79 |
| | | | 76 | 68 | |
| | | | 87 | 76 | .92 |
| | | | 78 | 69 | .58 |
| | | | 45 | 43 | .64 |
| | | | 64 | 59 | .60 |
| Budenz (2011)²³| CUNY quiet (%) | 22 | 77 | 90 | .075 |
| | CUNY noise (%) | | 62 | 77 | .05 |
| | CNC word (%) | | 45 | 57 | .03* |
| | CNC phoneme (%) | | 45 | 57 | .02* |
| | Sub analysis age ≥70 years | | | |
| | | | 12 | 25 | .03* |
| | | | 23 | 34 | .05* |
| Roberts (2012)²⁷| CNC (%) | 56 | 53.7 (0.42) | 54.3 (0.41) | .88 |
| Kamal (2014)²⁴| 4 choice spondee (%) | 20 | 78.8 (23) | 91.7 (16.2) | .12 |
| | High context sentence (%) | | 40.2 (37.1) | 62.7 (34.6) | .12 |
| | Monosyllabic identification (%) | | 27.5 (25.6) | 48.7 (23) | .02 |
| Mosnier (2014)¹⁸| Disyllabic words: SNR 0 dB (%) | 43 | 12 (2.8) | 25.4 (7.7) | <.005* |
| | Disyllabic words: SNR 5 dB (%) | | 23 (3.7) | 34 (3.2) | <.05* |
| Kraaijenga (2015)²⁵| CVC phoneme (%) | 182 | 189 | NR | NR | .867 |
| Sharpe (2016)²⁸| HINT (%) | 44 | 52 | NR | NR | NS |
| | CVC phoneme (%) | | | | NS | |
| | CVC word (%) | | | | NS | |
| | HINT (%) | | | | |
| | HINT (stnd)# (%) | | | | |
| | CVC phoneme (%) | | | | |
| | CVC words (%) | | | | |
| | Sub analysis age > 59 years | 32 | 75 (22) | 84 (18) | .06 |
| | | | 77 (21) | 86 (21) | .04* |
| | | | 65 (21) | 68 (18) | .25 |
| | | | 45 (22) | 52 (19) | .10 |
| | HINT (%) | Sub analysis age 18 – 52 years | 12 | 80 (23) | 77 (33) | .39 |
| | HINT (stnd)# (%) | | | | |
| | CVC phoneme (%) | | | | |
| | CVC word (%) | | | | |
| | Sub analysis age 18 – 52 years | 12 | 83 (24) | 78 (37) | .33 |
| | | | 72 (14) | 61 (29) | .10 |
| | | | 52 (21) | 52 (21) | .50 |
| Mohammed & Sarwat (2015)³¹| Arabic Speech Intelligibility (%) | 25 incl. adolescents | d | d | 32.5 (12.8) | 74.8 (16.1) | <.001* |

Data presented as mean score with standard deviation unless otherwise noted.
L, left; R, right; NR, not reported; NS, not significant; HINT, Hearing in noise test; CUNY, City University of New York; CNC, consonant-nucleus-consonant; SNR, speech noise ratio; CVC, consonant-vowel-consonant; stnd, standardised; four choice spondee test, closed set; high context sentence test, closed set with open end.

*Scores extracted from figures.
Standard error of mean (SEM) not accurately extractible.
Mean (SEM).
Total sample n = 24 left, n = 26 right.
*p-values <.05 were deemed statistically significant.
of six paediatric studies found a REA in one or more outcome measures. Five of eight adult studies found a REA in one or more outcome measures. Overall, in both children and adults, there is proof of a REA, although not indisputable because some studies do not see such a phenomenon, and all studies are largely affected by confounding factors. One study found very large differences in speech production capabilities between left ear and right ear implantees.\textsuperscript{31} As this study was deemed to have a high risk of bias, these results are probably an overestimation. Another study, investigating prelingually deafened children, did not correct for possible confounders such as age at implantation.\textsuperscript{29}

Two studies in this review analysed the effect of handedness and found no difference in results compared to the results of the total group.\textsuperscript{22,24} These findings are similar to the findings of Deguine et al who retrospectively investigated the effect of dominance in 111 patients (children and adults).\textsuperscript{22} Patients were dichotomised, based on CI implantation ipsilateral or contralateral to their dominant hand: left-handed=left ear implanted & right-handed=right ear implanted vs left-handed=left ear implanted & right-handed=right ear implanted. No differences in speech outcomes between groups were found. However, patients were not further subdivided into left-handed and right-handed patients and no adjustments were made for several potential confounders such as type of implant device, follow-up and age at implantation. Therefore, this study was not included in this systematic review. To sum up results from these three studies, handedness does not seem to be an influential factor in the existence of the REA. This could be explained by the fact that left-handed patients predominantly have a left hemisphere dominance just as the majority of right-handed patients (70%-80% vs 95%-98%), therefore handedness did not greatly alter the effect of side of implantation.

As mentioned previously, the heterogeneity in the study populations is high, which is likely to have influenced the results. Furthermore, due to heterogeneity in outcome measures and a lack of reporting of measures of uncertainty, no pooled analysis could be performed. In addition, the used outcome measures may not be sufficiently specific to detect a REA. As described in the introduction, a REA is most evident in dichotic listening tests. These can, however, only be used in subjects who are able to receive auditory stimuli in both ears, which is evidently not possible for unilaterally implanted patients with symmetrical severe-to-profound SNHL. Consequently, various outcome measures in left-implanted and right-implanted patients were compared. Finally, due to the retrospective design of the majority of the studies, it is not possible to correct for all the patient-related factors that may have influenced the observed outcome differences between patients with a left or right CI. A strength of this systematic review is the thorough systematic search of multiple databases with a broad search syntax and the extensive critical appraisal of the studies. Furthermore, we subdivided children and adults and incorporated the onset of acquisition of speech in the presentation and interpretation of the results.

5 | CONCLUSION

This systematic review investigated the effect of side of implantation in subjects with symmetrical SNHL after receiving a CI. The results of this review, though the level of evidence of included studies was low, revealed evidence for a REA in prelingually deafened children as well as postlingually deafened adults. Moreover, none of the studies identified a left ear advantage. In view of these results, we suggest that right ear implantation may be beneficial over left ear implantation in case of symmetrical SNHL and in the absence of other prognostic factors. Furthermore, this will be the practical side for most (right-handed) patients.

CONFLICT OF INTEREST

The authors do not have any competing interests.

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