REVIEWS

The Impact of Hearing Loss and Its Treatment on Health-Related Quality of Life Utility: a Systematic Review with Meta-analysis

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BACKGROUND: Hearing loss significantly impacts health-related quality of life (QoL), yet the effects of current treatments on QoL utility remain uncertain. Our objective was to describe the impact of untreated and treated hearing loss on QoL utility to inform hearing healthcare policy.

METHODS: We searched databases for articles published through 02/01/2021. Two independent reviewers screened for articles that reported elicitation of general QoL utility values for untreated and treated hearing loss health states. We extracted data and quality indicators from 62 studies that met the inclusion criteria.

RESULTS: Included studies predominately used observational pre/post designs (61%), evaluated unilateral cochlear implantation (65%), administered the Health Utilities Index 3 (HUI3; 71%), and were conducted in Europe and North America (84%). In general, treatment of hearing loss improved post-treatment QoL utility when measured by most methods except the EuroQoL 5 dimension (EQ-5D). In meta-analysis, hearing aids for adult mild-to-moderate hearing loss compared to no treatment significantly improved HUI3-estimated QoL utility (3 studies; mean change=0.11; 95% confidence interval (CI): 0.07 to 0.14) but did not impact EQ-5D-estimated QoL (3 studies; mean change=0.0; 95% CI: −0.03 to 0.04). Cochlear implants improved adult QoL utility 1-year post-implantation when measured by the HUI3 (7 studies; mean change=0.17; 95% CI: 0.11 to 0.23); however, pediatric VAS-estimated QoL utility was non-significant (4 studies; mean change=0.12; 95% CI: −0.02 to 0.25). The quality of included studies was limited by failure to report missingness of data and low survey response rates. Our study was limited by heterogeneous study populations and designs.

FINDINGS: Treatment of hearing loss significantly improves QoL utility, and the HUI3 and VAS were most sensitive to improvements in hearing. Improved access to hearing healthcare should be prioritized.

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KEY WORDS: cochlear implant; hearing aid; hearing loss; health state utility values; systematic review.

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INTRODUCTION

Nearly 1.5 billion people have hearing loss worldwide.[1] Unaddressed hearing loss has far-reaching consequences, adversely impacting quality of life, language development, social well-being, educational attainment, and occupational opportunities.[1, 2] However, the impact of hearing loss and its treatment on general patient-reported health-related quality of life (QoL) utility are poorly understood.[3, 4] A recent systematic review that only included RCTs identified two studies reporting QoL benefits of hearing aids, but did not report QoL utility.[3]

QoL utility values quantify patient preferences for health states and treatments.[5–8] Utility values generally include 0.0, indicating death, and 1.0, indicating perfect health, and are obtained through direct methods (i.e., elicitation through standard gamble or time trade-off) or indirect methods (e.g., a generic QoL questionnaire). Health state utility values differ

from routine measures of QoL in that each possible health state combination from a QoL measure is transformed into a utility value through scoring functions often based on preference experiments. QoL utilities may be used to calculate quality-adjusted life years (QALYs) as the effectiveness input in cost-effectiveness analysis, which is particularly important for hearing loss since interventions are aimed at improving QoL rather than survival.

High-quality utility values for hearing loss and its treatment will prove critical as policy makers consider possibilities for scale-up of hearing and other healthcare. This systematic review seeks to identify and synthesize current estimates of QoL utility values (from both RCTs and observational studies) for untreated and treated hearing loss and thereby to inform economic analyses and hearing healthcare clinical and policy decision-making.[9, 10] The key questions were as follows: (1) what are the patient-reported health state utility values for untreated hearing loss, and (2) what is the change in utility for the patient's general QoL utility after undergoing current treatments for hearing loss?

METHODS

This systematic utilized the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) checklist in its reporting (Appendix 1).[11] We registered our systematic review in PROSPERO (CRD42021253314). We collaborated with clinical and public health experts on the Lancet Commission on hearing loss[2,12] to define our key questions through three videoconference sessions.

Health State Mapping

As recommended by the National Institute for Health and Care Excellence (NICE) guidelines for systematic reviews of utility values, we mapped hearing loss health states with the Lancet Commission on Hearing Loss (Appendix 2). Hearing loss severity was defined by better-ear pure tone average hearing levels in decibels hearing level (dB HL), where mild was 26–40 dB HL, moderate was 41–60 dB HL, severe was 61–80 dB HL, and profound was 81 dB HL or greater. These severity strata were defined at the outset of the analysis, prior to publication of revised World Health Organization definitions.[13]

Literature Search and Article Selection

We consulted with a medical librarian to search PubMed, Embase, Scopus, CINAHL EBSCO, and Global Health EBSCO on 1 February 2021. Search terms were related to (1) hearing loss; (2) utility; and (3) quality of life (Appendix 3).

Inclusion criteria were full-length, peer-reviewed studies eliciting patient-reported health state utility values for hearing loss health states that included ≥20 patients (see Appendix 4 for a completed Population, Intervention, Comparison, Outcomes framework). We included RCTs and observational studies. Articles were screened for inclusion at the abstract and full-text levels by two independent reviewers (EDB, KK, NF, GZ, MKH). We excluded articles that derived utility for conditions with significant quality of life effects other than hearing loss (e.g., Meniere's disease) and articles where hearing loss was not audiometrically confirmed. The two independent reviewers screened all articles, and inclusion/exclusion conflicts were resolved by discussion or a third investigator.

Data and Extraction

We used guidelines published by the NICE to guide our data collection.[14] We extracted data related to setting and population, treatment status, study design, hearing loss severity and laterality, utility measure, outcome type, and utility estimate values in utils (EDB, KK, NF, GZ, MKH). All extractions were reviewed by a second investigator (EDB, KK, NF), with disagreements settled by a third investigator.

Quality Assessment

One investigator extracted quality indicators (EDB, KK, NF, MKH), and a second investigator independently read the articles and reviewed the extractions (EDB, KK).[14] Disagreements were resolved by consensus or a third investigator. We operationalized a NICE quality measure where we evaluated each of the following criteria: (1) sample size ≥ 100; (2) description of respondent selection and recruitment; (3) description of inclusion/exclusion criteria; (4) description of response rate and response rate ≥ 60%; (5) reporting of attrition/loss to follow-up (for longitudinal studies only); (6) reporting of missingness of data and approaches to handle missingness; and (7) appropriateness of measure (Appendix 5).[15, 16] We report whether each individual study met quality criteria 1–7 in Appendix 6, and qualitatively assessed the overall quality of included studies.

Data Synthesis and Analysis

In the text, we summarized data of studies able to be synthesized quantitatively and other results are in Appendix 8. Quantitative data synthesis was undertaken if ≥3 studies used identical measures to report health state utility values in a sufficiently homogenous way with respect to population, health state, and study design. Our primary outcome was mean change in health state utility values between hearing loss health states. Variables used to group populations included age (< or ≥18 years), hearing health state, and treatment status. We synthesized health state utility values obtained closest to a maximum of 1 year of follow-up after receiving a hearing aid or a cochlear implant, and also synthesized measures obtained at the longest point of follow-up beyond 1 year. When studies reported pre/post scores only, we calculated the mean change score as the difference in post minus pre means, and the change score variance utilizing pre and post variances and

assuming a conservative 0.5 correlation. We transformed median and range/IQR change scores into means and standard deviations.[17] We used a random-effects restricted maximum-likelihood (REML) estimator, in R statistical package (The R Foundation; metafor meta-analysis library, version 1.9-7), to generate summary values and the Knapp-Hartung approach to further adjust standard errors.[18, 19]

Role of the Funding Source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

RESULTS

Summary of Included Studies

Our search yielded 1561 articles, from which 64 articles representing 62 studies met the inclusion criteria (Fig. 1; Tables 2 and 3). Studies were predominantly conducted in Europe (*n*=34, 55%) and North America (*n*=18, 29%). Few studies were conducted in other regions: Africa (*n*=2, 3%); Asia (*n*=7, 11%); Australia and New Zealand (*n*=4, 6%); and South America (*n*=1, 2%; Table 1). Forty-eight studies evaluated hearing loss strategies exclusively in adult populations (77%), 13 in pediatric populations (21%), and one included both (2%). Observational pre/post was the most common study design (*n*=38, 61%), followed by comparative and non-comparative cross-sectional studies (*n*=18, 29%). Studies assessed multi-attribute utility values using the Assessment of Quality of Life (AQoL; *n*=2; 3%), Euro-Qol 5-Dimension (EQ-5D; *n*=15, 24%); Euro-Qol-5 Dimension 5 Level (EQ-5D-5L; *n*=1, 2%), Health Utilities Index 3 (HUI3; *n*=44, 71%), Health Utilities Index 2 (HUI2; *n*=5, 8%), Pediatric Quality of Life Inventory (PedsQL; *n*=1, 2%), or Quality Well-being Scale (QWB; *n*=1, 2%). Studies directly elicited health state utility values using time trade-off (TTO; *n*=5, 8%) and

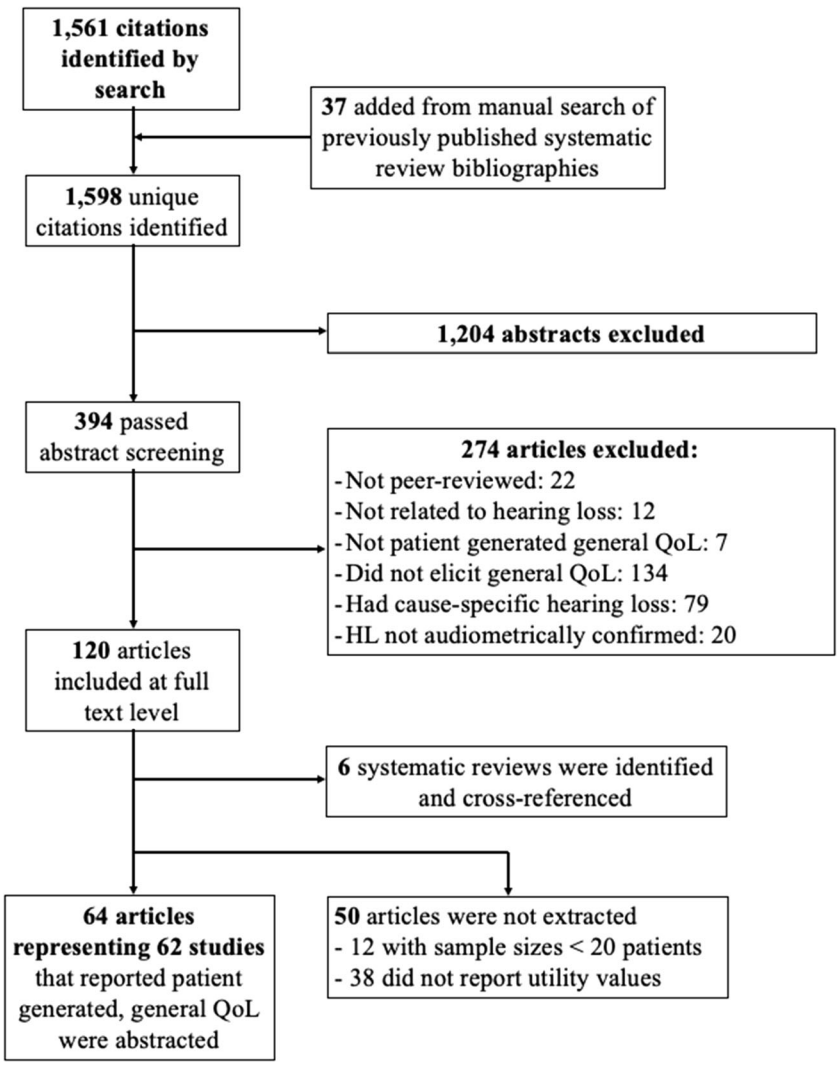

Figure 1 Literature flow diagram. The figure depicts the flow of studies from search identification to eventual inclusion or exclusion in the systematic review. We manually searched references of previously published systematic reviews identified through our search strategy for potentially relevant articles to include for assessment at the Abstract level. QoL, health-related quality of life.

Table 1 Study Characteristics

Characteristic	Number of Studies (n=62 in all)*
Continent	
Europe	34 (55%)
North America	18 (29%)
Asia	7 (11%)
Australia and New Zealand	4 (6%)
Africa	2 (3%)
South America	1 (2%)
Population	
Pediatric only	13 (21%)
Adult only, >18y	48 (77%)
Both	1 (2%)
Health Utility Measure Used	
Multi-attribute Utility Instruments	
Assessment of Quality of Life (AQoL)	2 (3%)
EuroQol-5 Dimension (EQ-5D)	15 (24%)
EuroQol-5 Dimension 5-Level (EQ-5D-5L)	1 (2%)
Health Utilities Index 3 (HUI3)	44 (71%)
Health Utilities Index 2 (HUI2)	5 (8%)
Pediatric Quality of Life Inventory (PedsQL)	1 (2%)
Quality Wellbeing Scale (QWB)	1 (2%)
Direct elicitation	
Time Trade-Off (TTO)	5 (8%)
Visual Analog Scale (VAS)	15 (24%)
Discrete Choice Experiment, reported in Disability-Adjusted Life Years†	2 (3%)
Hearing Loss Severity	
Mild	7 (11%)
Moderate	17 (27%)
Severe	10 (16%)
Profound	45 (73%)
Unspecified	2 (3%)
No Hearing Loss	2 (3%)
Treatment Type	
Untreated	10 (16%)
Acoustic hearing aids	12 (19%)
Implantable hearing aids	5 (8%)
Unilateral cochlear implants	40 (65%)
Bilateral cochlear implants	6 (10%)
Bimodal	4 (6%)

**Not all categories sum to 62 (or 100%) as some studies may be represented more than once*

†The Global Burden of Disease used discrete choice experiments to calculate disability weights for disability-adjusted life years for all conditions in their study, including hearing loss

visual analog scale (VAS; n=15, 24%) methods. Two studies (3%) reported disutility in DALYs using discrete choice experiment (DCE) methods. The most common treatment was unilateral cochlear implantation (n=40, 65%). Other treatments were acoustic hearing aids (n=12, 19%), implantable hearing aids (n=5, 8%), bilateral cochlear implantation (n=6, 10%), and bimodal stimulation (cochlear implant + contralateral hearing aid) (n=4, 6%). Ten studies (16%) included untreated hearing loss, and in four studies, the treatment status was not described (6%).

Quality of Included Studies

The most frequent quality deficits identified in included studies were failure to report missing data and/or approaches to deal with it (n=39, 63%) and failure to report response rate and/or have a response rate ≥60% (n=22, 35%) (Appendix 6). While sample size is generally a poor indicator of study quality, utility values used for population-level decision-making should be measured in a representative sample and 58% of included studies had sample sizes <100.

Untreated Hearing Loss

Ten studies (11 articles)[20–30] reported utility values for untreated hearing loss health states, with one reporting untreated hearing loss in children (Table 2).[30] Two large cross-sectional studies assessed DALY effects of hearing loss using DCE techniques, reporting utility value decrements of 0.005 to 0.010 for mild hearing loss, 0.023 to 0.027 for moderate hearing loss, 0.032 to 0.158 for severe hearing loss, 0.031 to 0.204 for profound hearing loss, and 0.033 to 0.215 for complete hearing loss compared to no hearing loss.[27, 28] Two studies measured utility of hearing loss in a large population-based Korean adult sample using the EQ-5D and VAS, but the treatment status was not described.[31, 32] One study compared the utility of no hearing loss to moderate, severe, and profound hearing loss in children, but treatment status was unclear.[30]

The remaining studies assessed utility in persons without hearing loss treatment without a comparison group. Adult studies reported EQ-5D-estimated utility for untreated mild hearing loss (range: 0.790 to 0.840) and untreated moderate hearing loss (range: 0.690 to 0.870).[20, 21, 23, 24] In general, studies using the HUI3 yielded lower utility estimates for both mild (range: 0.560 to 0.713) and moderate (range: 0.560 to 0.647) untreated hearing loss as compared to estimates generated by the EQ-5D and SF-6D.[20, 22, 25, 26, 29]

Acoustic Hearing Aids

Three studies with a pre/post design measured the effect of hearing aids for mild-to-moderate adult hearing loss on QoL using the HUI3 (Appendix 7, Fig. 2A, Table 3).[22, 25, 26] In meta-analysis, hearing aids significantly improved adult QoL utility when measured by the HUI3 (mean change=0.11; 95% confidence interval (CI): 0.07–0.14). However, in three studies that measured change in QoL utility after hearing aid using the EQ-5D, no significant benefit was seen (Appendix 7, Fig. 2B; mean change=0.0; 95% CI: −0.03 to 0.04).[23, 24, 26, 33] One study included in both syntheses used the HUI3 and the EQ-5D in their population, finding mean change scores of 0.12 (standard error, SE=0.02) with the HUI3 and 0.01 with the EQ-5D (SE=0.02).[26] Additionally, one RCT found improved 3-month HUI3-estimated QoL utility for early (mean utility=0.77, SD=0.19) vs. delayed (mean=0.65, SD=0.25) fittings of hearing aids for persons identified through screening as having mild-to-moderate hearing loss.[22] Four additional observational pre/post studies used VAS, HUI2, and SF-6D to assess the utility impact of hearing aids in adults with mild-to-moderate hearing loss.[23–26, 33] One cross-sectional study measured QoL using the EQ-5D in patients primarily using hearing aids.[34] Two studies evaluated hearing aid treatment in children, although neither compared hearing aid use to no treatment.[35, 36]

Table 2 Summary of Studies Reporting Utility Values for Untreated Hearing Loss

Reference	Population	Hearing Loss Severity	Setting	Study Design	Comparison	Follow-up Time (months)	Utility Instrument	Main Results
Untreated								
Barton et al. 2005[20]	Adult	Mild	Europe	Cross-sectional	No Comparison (*n*=915)	N/A	HUI3, SF-6D, EQ-5D	The mean utility using HUI3 was 0.56, 95% CI [0.55, 0.57]. The mean utility using SF-6D was 0.77, 95% CI [0.76, 0.77]. The mean utility using EQ-5D was 0.79, 95% CI [0.78, 0.81].
Davis et al. 2007[25]	Adult	Mild	Europe	Observational, pre/post	A. Untreated (HUI3 group, *n*=116; SF-6D group, *n*=95) B. Hearing Aids (HUI3 group, *n*=116; SF-6D group, *n*=95)	3	HUI3, SF-6D	Mean utility using HUI3 was 0.713 (variance unclear) for the untreated state, and 0.79 (SD 0.2) after hearing aids. The mean utility change using HUI3 was 0.075 (SE 0.019). Mean utility using SF-6D was 0.744 (variance unclear) for the untreated state, and 0.759 (SD 0.15) after hearing aids. The mean utility change using SF-6D was 0.016 (SD 0.0079).
Grutters et al. 2007[26]	Adult	Moderate	Europe	Observational, pre/post	A. Untreated (BEPTA <35 dB, *n*= 69; non-applicants, *n*=46; first-time hearing aid applicants, *n*=108; hearing aid re-applicants, *n*=65) B. Hearing Aids, *n*=70	6	HUI2, HUI3, EQ-5D	The median untreated utility using HUI2 was 0.80 (IQR 0.20) for patients with baseline BEPTA <35 dB, 0.78 (IQR 0.15) for non-applicants, 0.78 (IQR 0.16) for first-time applicants, and 0.79 (IQR 0.17) for re-applicants. The median untreated utility using HUI3 was 0.66 (IQR 0.37) for patients with baseline BEPTA <35 dB, 0.60 (IQR 0.41) for non-applicants, 0.61 (IQR 0.28) for first-time applicants, and 0.61 (IQR 0.41) for re-applicants. The median untreated utility using EQ-5D was 0.81 (IQR 0.27) for patients with baseline BEPTA <35 dB, 0.87 (IQR 0.27) for non-applicants, 0.85 (IQR 0.27) for first-time applicants, and 0.85 (IQR 0.27) for re-applicants. Mean utility change with hearing aids was 0.12 (SD 0.18) on HUI3, 0.01 (SD 0.13) on EQ-5D, and 0.07 (SD 0.13) on HUI2.
Joore et al. 2002[21]	Adult	Moderate	Europe	Observational, pre/post	A. Untreated (*n*=77) B. Hearing Aids (*n*=77)	3, 6.25	EQ-5D	The mean untreated utility was 0.69 (SD 0.17) at baseline, 0.71 (SD 0.15) with hearing aids at 3-month follow-up and remained unchanged at 6.25 months (0.71, SD 0.15).
Kaur et al. 2020[22]	Adult	Moderate	Asia	Randomized controlled trial	A. Untreated (immediately fitted, *n*=264; delayed start, *n*=163) B. Hearing Aids (immediately fitted, *n*=264; delayed start, *n*=163)	3, 6	HUI3	The mean utility at baseline was 0.6432 (SD 0.222) for the group immediately fitted with hearing aids and 0.6501 (SD 0.250) for the delayed start group. The mean utility at 3 months for the group immediately fitted (post hearing aid fitting) was 0.7657 (SD 0.188) and 0.6487 (SD 0.235) for the delayed start group (untreated).

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Table 2. (continued)

Reference	Population	Hearing Loss Severity	Setting	Study Design	Comparison	Follow-up Time (months)	Utility Instrument	Main Results
								The mean utility at 6 months for the delayed start group, after fitting, was 0.7551 (SD 0.193).
Petrou et al. 2007[30]	Pediatric	No hearing loss, Moderate, Severe, Profound	Europe	Cross-sectional	A. No hearing loss (*n*=63) B. Unclear treatment (moderate, *n*=65; severe, *n*=29; profound, *n*=26)	N/A	HUI3	The mean utility was 0.920 (SD 0.149) for the group with no hearing loss, 0.702 (SD 0.309) for moderate hearing loss, 0.476 (SD 0.335) for severe hearing loss, and 0.602 (SD 0.269) for profound hearing loss.
Salomon et al. 2012[28]	Adult	Mild, Moderate, Severe, Profound	Asia, North America, South America	Cross-sectional	No Comparison (*n*=30,230)	N/A	DALY	The mean DALY was 0.005, 95% CI [0.002, 0.012] for mild hearing loss, 0.023, 95% CI [0.013, 0.038] for moderate hearing loss, 0.032, 95% CI [0.018, 0.051] for severe hearing loss, 0.031, 95% CI [0.018, 0.049] for profound hearing loss, and 0.033, 95% CI [0.020, 0.052] for complete hearing loss.
Salomon et al. 2015[27]	Adult	Mild, Moderate, Severe, Profound	Europe	Cross-sectional	No Comparison (*n*=30,660)	N/A	DALY	The mean DALY was 0.01, 95% CI [0.004, 0.019] for mild hearing loss, 0.027, 95% CI [0.015, 0.042] for moderate hearing loss, 0.158, 95% CI [0.105, 0.227] for severe hearing loss, 0.204, 95% CI [0.134, 0.288] for profound hearing loss, and 0.215, 95% CI [0.144, 0.307] for complete hearing loss.
Summerfield et al. 2002[29]	Adult	Profound	Europe	Observational, pre/post	A. Untreated (*n*=87) B. Hearing Aids (*n*=115) C. Cochlear Implantation (traditional candidate, *n*=87; marginal hearing aid user, *n*=115)	6	HUI3	The mean utility was 0.562, 95% CI [0.527, 0.596] before cochlear implantation (untreated), and 0.75, 95% CI [0.705, 0.794] after implantation. The mean utility change was 0.188, 95% CI [0.15, 0.226] for traditional cochlear implant users. The mean utility was 0.725, 95% CI [0.693, 0.757] with hearing aids, and 0.802, 95% CI [0.767, 0.838] after implantation. The mean utility change after cochlear implantation was 0.077, 95% CI [0.045, 0.11] for those attaining some benefit from HAs.
Vuorialho et al. 2006 (1)[23]	Adult	Moderate	Europe	Observational, pre/post	A. Untreated (*n*=98) B. Hearing Aids (*n*=98)	6	EQ-5D, VAS	The mean untreated utility using EQ-5D was 0.70 (SD 0.19) at baseline and 0.7 (SD 0.18) at 6 months follow-up after hearing aids. The mean untreated utility using VAS was 0.61 (SD 0.179) at baseline, and 0.65 (SD 0.163) at 6 months follow-up after hearing aids.
Vuorialho et al. 2006 (2)[24]	Adult	Moderate	Europe	Observational, pre/post	A. Untreated (*n*=98) B. Hearing Aids (*n*=98)	12	EQ-5D, VAS	The mean untreated utility on EQ-5D was 0.70 (SD 0.18) at baseline and 0.68 (SD 0.20) at 12 months follow-up after hearing aids. The mean untreated utility using VAS was 0.614 (SD 0.165) at baseline and 0.647 (SD 0.155) at 12 months follow-up after hearing aids.

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Table 2. (continued)

Reference	Population	Hearing Loss Severity	Setting	Study Design	Comparison	Follow-up Time (months)	Utility Instrument	Main Results
Unclear Treatment*								
Baek et al. 2016[31]	Adult	No hearing loss, Mild, Moderate	Asia	Cross-sectional	A. No hearing loss (*n*=1757) B. Mild (*n*=890) C. Moderate (*n*=13,802)	N/A	EQ-5D, VAS	The mean utility using EQ-5D was 0.96 (SE 0.00) for the group with no hearing loss, 0.88 (SE 0.00) for mild hearing loss, and 0.86 (SE 0.01) for moderate hearing loss. The mean utility using VAS was 0.751 (SE 0.0018) for the group with no hearing loss, 0.6748 (SE 0.0063) for mild hearing loss, and 0.6624 (SE 0.0092) for moderate hearing loss.
Barton et al. 2006[69]	Pediatric	Moderate, Severe, Profound	Europe	Cross-sectional	A. Unclear (AHL 40–70 dB, *n*=260; AHL 71–95 dB, *n*=464; AHL 96–106 dB, *n*=259; AHL > 105 dB, *n*=290) B. Cochlear Implantation (*n*=403)	N/A	HUI3	The treatment state was unclear for patients with moderate, profound, or severe hearing loss. The mean utility was 0.677, 95% CI [0.652, 0.702] for moderate hearing loss, 0.616, 95% CI [0.598, 0.634] for severe hearing loss, 0.497, 95% CI [0.469, 0.525] for profound hearing loss between 96 and 106 dB, and 0.353, 95% CI [0.327, 0.379] for profound hearing loss greater than 105 dB. The mean utility was 0.575, 95% CI [0.553, 0.598] for the cochlear implant group.
Kwon et al. 2018[32]	Adult	Moderate	Asia	Cross-sectional	No Comparison (*n*=23,297)	N/A	EQ-5D	The mean difference in utility between hearing loss (defined as >40 dB BEPTA) and non-hearing loss groups was −0.0224, 95% CI [−0.0363, −0.0086].
Le et al. 2020[35]	Pediatric	Mild, Moderate, Severe, Profound	Australia/ New Zealand	Observational, not pre/post	A. Hearing Aid (mild, *n*=22; moderate, *n*=27) B. Unclear (severe, *n*=13; profound, *n*=36)	N/A	HUI3	The mean utility was 0.73 (SD 0.25) for mild hearing loss with hearing aids, 0.76 (SD 0.16) for moderate hearing loss with hearing aids, 0.53 (SD 0.31) for severe hearing loss (treatment unclear), and 0.61 (SD 0.29) for profound hearing loss (treatment unclear).
Petrou et al. 2007[30]	Pediatric	No hearing loss, Moderate, Severe, Profound	Europe	Cross-sectional	A. No hearing loss (*n*=63) B. Unclear (moderate, *n*=65; severe, *n*=29; profound, *n*=26)	N/A	HUI3	The mean utility was 0.920 (SD 0.149) for the group with no hearing loss, 0.702 (SD 0.309) for moderate hearing loss, 0.476 (SD 0.335) for severe hearing loss, and 0.602 (SD 0.269) for profound hearing loss.
Turunen-Taheri et al. 2017[34]	Adults with concomitant vision loss	Severe	Europe	Cross-sectional	No Comparison (*n*=1742)	N/A	EQ-5D	The mean utility was 0.6 (SD 0.3).

**We included unclear hearing loss health states in the untreated table as we assumed the vast majority of persons with hearing loss, and especially those with mild-to-moderate hearing loss, do not receive treatment*

Abbreviations: AHL average hearing loss, BEPTA better-ear pure tone average, CI confidence interval, DALY disability-adjusted life year, dB decibel, EQ-5D EuroQol-5 Dimension, EQ-5D-5L EuroQol-5 Dimension 5-Level, HUI3 Health Utilities Index 3, N/A not applicable, SD standard deviation, SE standard error, SF-6D Short-Form Six-Dimension, VAS visual analog scale

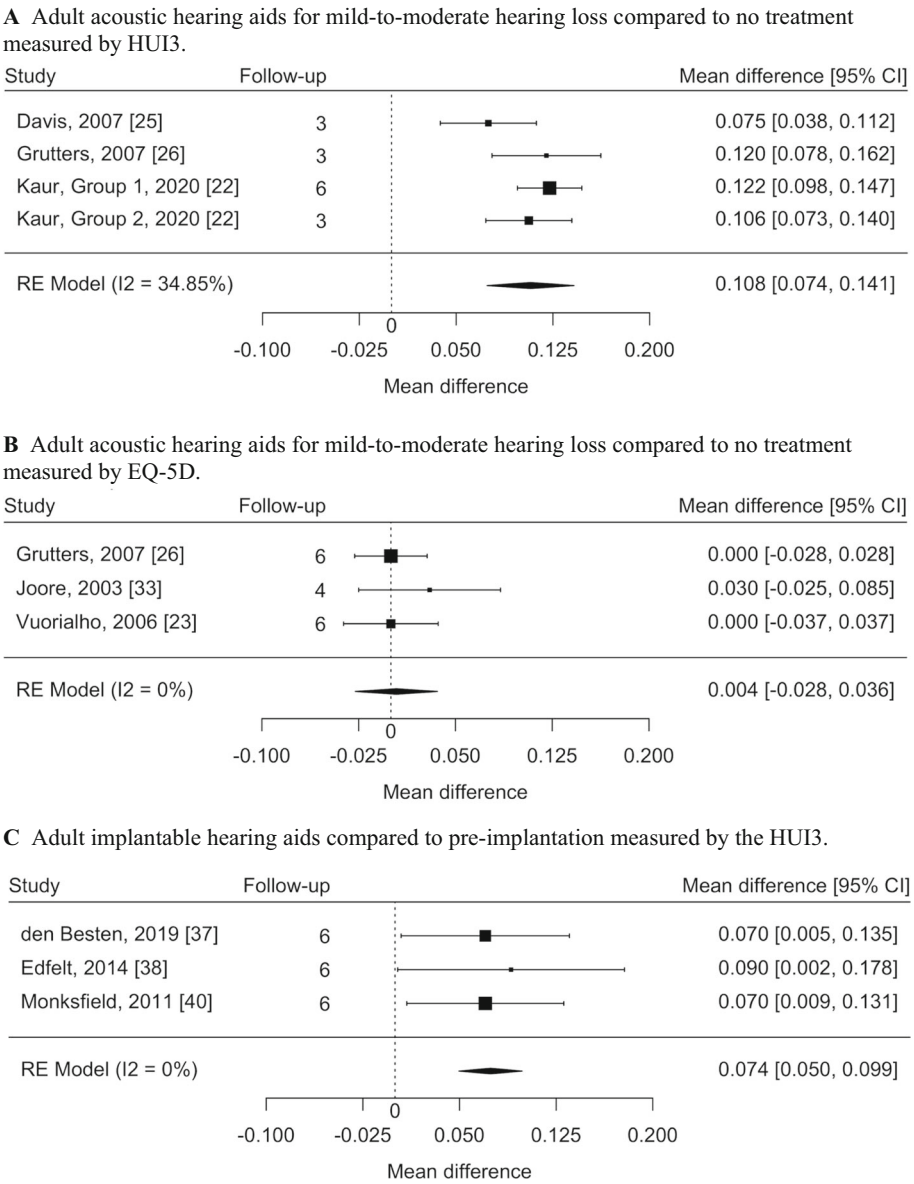

Figure 2 Hearing aid meta-analyses. The figure presents the forest plots for meta-analyses of mean change scores for (A) adult acoustic hearing aids for mild-to-moderate hearing loss compared to no treatment measured by HUI3, (B) adult acoustic hearing aids for mild-to-moderate hearing loss compared to no treatment measured by EQ-5D, and (C) adult implantable hearing aids compared to pre-implantation measured by the HUI3. Estimates to the right of the x-axis show a positive utility increase after intervention. CI, confidence interval; RE, random effects.

Implantable Hearing Aids

Four studies compared implantable hearing aid health states to pre-implantation states in adults with moderate-to-severe hearing loss, all using a pre/post design (Table 3).[37–40] In meta-analysis, three studies found an HUI3-estimated mean change of 0.07 after receipt of an implantable hearing aid (Appendix 7, Fig. 2C; 95% CI: 0.05 to 0.10).[37, 38, 40] Another study did not find a significant benefit of implantable hearing aids or bone conduction hearing aids (the latter using stimulators on the skin surface) compared to non-implanted acoustic hearing aids.[39] One cross-sectional study in Europe evaluated utility in pediatric patients with implantable hearing aids (Appendix 8).[41]

Adult Cochlear Implantation

Seventeen studies assessed the impact of cochlear implantation compared to pre-cochlear implantation (with a mix of hearing aid use prior to implantation) in adults with bilateral severe-to-profound hearing loss using the HUI3 and a pre/post design (Table 4).[29, 42–57] The mean change in HUI3-estimated utility after cochlear implantation was 0.16 (11 studies; 95% CI: 0.14 to 0.19; Appendix 7, Fig. 3A) when measured 1 year or less from the time of implantation, and 0.17 when measured beyond 1 year after implantation (7 studies; 95% CI: 0.11 to 0.23; Appendix 7, Fig. 3B). Three studies were unable to be included in meta-analysis due to no data reported on variance.[46, 55, 57]

Table 3 Summary of Studies Reporting Utility Values for Persons with Hearing Loss and Using Hearing Aids

Reference	Population	Hearing Loss Severity	Setting	Study Design	Comparison	Follow-up Time (months)	Utility Instrument	Main Results
Acoustic Hearing Aids								
Buchman et al. 2020[78]	Adult	Profound	North America	Observational, pre/post	A. Bimodal (*n*=96) B. Hearing Aids (*n*=96)	6	HUI3	The mean utility at baseline using hearing aids was 0.46, 95% CI [0.42, 0.50]. The mean utility after bimodal stimulation was 0.64, 95% CI [0.60, 0.68] and the mean utility change was 0.18, 95% CI [0.14, 0.22].
Davis et al. 2007[25]	Adult	Mild	Europe	Observational, pre/post	A. Untreated (HUI3 group, *n*=116; SF-6D group, *n*=95) B. Hearing Aids (HUI3 group, *n*=116; SF-6D group, *n*=95)	3	HUI3, SF-6D	Mean utility using HUI3 was 0.713 (variance unclear) for the untreated state, and 0.79 (SD 0.2) after hearing aids. The mean utility change using HUI3 was 0.075 (SE 0.019). Mean utility using SF-6D was 0.744 (variance unclear) for the untreated state, and 0.759 (SD 0.15) after hearing aids. The mean utility change using SF-6D was 0.016 (0.0079).
Grutters et al. 2007[26]	Adult	Moderate	Europe	Observational, pre/post	A. Untreated (BEPTA <35 dB, *n*= 69; non-applicants, *n*=46; first-time hearing aid applicants, *n*=108; hearing aid re-applicants, *n*=65) B. Hearing Aids, *n*=70	6	HUI2, HUI3, EQ-5D	The median untreated utility using HUI2 was 0.80 (IQR 0.20) for patients with baseline BEPTA <35 dB, 0.78 (IQR 0.15) for non-applicants, 0.78 (IQR 0.16) for first-time applicants, and 0.79 (IQR 0.17) for re-applicants. The median untreated utility using HUI3 was 0.66 (IQR 0.37) for patients with baseline BEPTA <35 dB, 0.60 (IQR 0.41) for non-applicants, 0.61 (IQR 0.28) for first-time applicants, and 0.61 (IQR 0.41) for re--applicants. The median untreated utility using EQ-5D was 0.81 (IQR 0.27) for patients with baseline BEPTA <35 dB, 0.87 (IQR 0.27) for non--applicants, 0.85 (IQR 0.27) for first-time applicants, and 0.85 (IQR 0.27) for re--applicants. Mean utility change with hearing aids was 0.12 (SD 0.18) on HUI3, 0.01 (SD 0.13) on EQ-5D, and 0.07 (SD 0.13) on HUI2.
Joore et al. 2002[21]	Adult	Moderate	Europe	Observational, pre/post	A. Untreated (*n*=77) B. Hearing Aids (*n*=77)	3, 6.25	EQ-5D	The mean untreated utility was 0.69 (SD 0.17) at baseline, 0.71 (SD 0.15) with hearing aids at 3-month follow-up and remained unchanged at 6.25 months (0.71, SD 0.15).
Joore et al. 2003[33]	Adult	Moderate	Europe	Observational, pre/post	A. Untreated (*n*=126) B. Hearing Aids (*n*=126)	4	EQ-5D, VAS	The mean utility change after hearing aid fitting for EQ-5D was 0.03, 95% CI [−0.03, 0.08]. The mean utility change after hearing aid fitting for VAS was 0.02, 95% CI [−0.02, 0.05].
Kaur et al. 2020[22]	Adult	Moderate	Asia	Randomized controlled trial	A. Untreated (immediately fitted, *n*=264; delayed start, *n*=163) B. Hearing Aids (immediately fitted, *n*=264; delayed start, *n*=163)	3, 6	HUI3	The mean utility at baseline was 0.6432 (SD 0.222) for the group immediately fitted with hearing aids and 0.6501 (SD 0.250) for the delayed start group. The mean utility at 3 months for the group immediately fitted (post hearing aid fitting)

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Table 3. (continued)

Reference	Population	Hearing Loss Severity	Setting	Study Design	Comparison	Follow-up Time (months)	Utility Instrument	Main Results
								was 0.7657 (SD 0.188) and 0.6487 (SD 0.235) for the delayed start group (untreated). The mean utility at 6 months for the delayed start group, after fitting, was 0.7551 (SD 0.193).
Le et al. 2020[35]	Pediatric	Mild, Moderate, Severe, Profound	Australia/ New Zealand	Observational, not pre/post	A. Hearing Aids (mild, *n*=22; moderate, *n*=27) B. Unclear (severe, *n*=13; profound, *n*=36)	NA	HUI3	The mean utility was 0.73 (SD 0.25) for mild hearing loss with hearing aids, 0.76 (SD 0.16) for moderate hearing loss with hearing aids, 0.53 (SD 0.31) for severe hearing loss (treatment unclear), and 0.61 (SD 0.29) for profound hearing loss (treatment unclear).
Smith-Olinde et al. 2008[36]	Pediatric	Moderate, Profound	North America	Cross-sectional	A. Hearing Aids (PTA 42.6, *n*=22; PTA 58.3, *n*=34; PTA 83.4, *n*=19) B. Cochlear Implantation (PTA 95.6, *n*=28)	N/A	HUI3, QWB	The mean utility using HUI3 was 0.707 (SD 0.18) for the group with PTA 42.6, 0.615 (SD 0.22) for the group with PTA 58.3, 0.54 (SD 0.22) for the group with PTA 83.4, and 0.609 (SD 0.16) for the group with PTA 95.6. The mean utility using QWB was 0.645 (SD 0.12) for the group with PTA 42.6, 0.589 (SD 0.11) for the group with PTA 58.3, 0.551 (SD 0.07) for the group with PTA 83.4, and 0.613 (SD 0.09) for the group with PTA 95.6.
Summerfield et al. 2002[29]	Adult	Profound	Europe	Observational, pre/post	A. Untreated (*n*=87) B. Hearing Aids (*n*=115) C. Cochlear Implantation (traditional candidate, *n*=87; marginal hearing aid user, *n*=115)	6	HUI3	The mean utility was 0.562, 95% CI [0.527, 0.596] before cochlear implantation (untreated), and 0.75, 95% CI [0.705, 0.794] after implantation. The mean utility change was 0.188, 95% CI [0.15, 0.226] for traditional cochlear implant users. The mean utility was 0.725, 95% CI [0.693, 0.757] with hearing aids, and 0.802, 95% CI [0.767, 0.838] after implantation. The mean utility change after cochlear implantation was 0.077, 95% CI [0.045, 0.11] for those attaining some benefit from HAs.
Vuorialho et al. 2006 (1)[23]	Adult	Moderate	Europe	Observational, pre/post	A. Untreated (*n*=98) B. Hearing Aids (*n*=98)	6	EQ-5D, VAS	The mean untreated utility using EQ-5D was 0.70 (SD 0.19) at baseline and 0.7 (SD 0.18) at 6 months follow-up after hearing aids. The mean untreated utility using VAS was 0.61 (SD 0.179) at baseline, and 0.65 (SD 0.163) at 6 months follow-up after hearing aids.
Vuorialho et al. 2006 (2)[24]	Adult	Moderate	Europe	Observational, pre/post	A. Untreated (*n*=98) B. Hearing Aids (*n*=98)	12	EQ-5D, VAS	The mean untreated utility on EQ-5D was 0.70 (SD 0.18) at baseline and 0.68 (SD 0.20) at 12 months follow-up after hearing aids. The mean untreated utility using VAS was 0.614 (SD 0.165) at baseline and 0.647 (SD 0.155) at 12 months follow-up after hearing aids.
Wick et al. 2002[79]	Adult	Severe	North America	Observational, pre/post	A. Hearing Aids (*n*=70) B. Bimodal (*n*=70)	6	HUI3	The mean utility at baseline using hearing aids alone was 0.428, 95% CI [0.379, 0.478]. The mean utility was 0.614, 95% CI [0.564, 0.663] 6 months after bimodal stimulation. The mean utility change was 0.186, 95% CI [0.136, 0.234].

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Table 3. (continued)

Reference	Population	Hearing Loss Severity	Setting	Study Design	Comparison	Follow-up Time (months)	Utility Instrument	Main Results
Implantable Hearing Aids								
den Besten et al. 2019[37]	Adult	Moderate	North America	Observational, pre/post	A. Pre-BAHA (patients with single-sided sensorineural deafness, *n*=15; patients with conductive/mixed hearing loss, *n*=37) B. BAHA (*n*=14, *n*=36)	6	HUI3	The mean utility for participants with conductive/mixed hearing loss was 0.67 (SD 0.21) pre-BAHA and 0.74 (SD 0.199) post-BAHA. The mean utility for participants with single-sided sensorineural deafness was 0.65 (SD 0.32) pre-BAHA and 0.70 (SD 0.29) post-BAHA.
de Wolf et al. 2011[41]	Pediatric	Moderate	Europe	Cross-sectional	A. Unilateral BAHA (*n*=15) B. Bilateral BAHA (*n*=10)	N/A	HUI3	The mean utility for the unilateral BAHA group was 0.82 (SD 0.12) and 0.83 (SD 0.14) for the bilateral group.
Edfeldt et al. 2014[38]	Adult	Severe	Europe	Observational, pre/post	A. Pre-BAHA (*n*=24) B. BAHA (*n*=24)	6, 8	HUI2, HUI3	The mean utility using HUI2 was 0.72 (SD 0.18) pre-BAHA and 0.82 (SD 0.16) after BAHA (6 months). The mean utility using HUI3 was 0.57 (SD 0.20) pre-BAHA and 0.66 (SD 0.23) after BAHA (8 months).
Hol et al. 2004[39]	Adult	Severe	Europe	Observational, pre/post	A. Hearing Aids (*n*=36) B. CBHA (*n*=20) C. BAHA (*n*=20, 36)	6	EQ-5D, VAS	The mean utility using EQ-5D was 0.78 (SD 0.17) for patients using HAs pre-implantation and 0.77 (SD 0.17) after BAHA. The mean utility using EQ-5D was 0.71 (SD 0.23) for patients using CBHAs pre-implantation and 0.70 (SD 0.19) after BAHA. The mean utility using VAS was 0.761 (SD 0.141) for patients using HAs pre-implantation and 0.734 (SD 0.171) after BAHA. The mean utility using VAS was 0.740 (SD 0.160) for patients using CBHAs pre-implantation and 0.724 (SD 0.174) after BAHA.
Monksfield et al. 2011[40]	Adult	Moderate	Europe	Observational, pre/post	A. Pre-BAHA (*n*=70) B. BAHA (*n*=70)	6	HUI3	The mean utility before BAHA was 0.66, 95% CI [0.53, 0.65] and after BAHA was 0.59, 95% CI [0.60, 0.72].

Abbreviations: BAHA bone anchored hearing aid, BEPTA better-ear pure tone average, CBHA conventional bone conduction hearing aid, CI Confidence Interval, dB decibel, EQ-5D EuroQol-5 Dimension, HUI2 Health Utilities Index 2, HUI3 Health Utilities Index 3, IQR interquartile range, N/A not applicable, PTA pure tone average, QWB Quality Wellbeing Scale, SD standard deviation, SE standard error, SF-6D Short-Form Six-Dimension, VAS visual analog scale

Table 4 Summary of Studies Reporting Utility Values for Persons with Hearing Loss and Using Cochlear Implants

Reference	Population	Hearing Loss Severity	Setting	Study Design	Comparison	Follow-up Time (months)	Utility Instrument	Main Results
Cochlear Implantation*								
Arnoldner et al. 2014 (1) [43]	Adult	Profound	North America	Observational, pre/post	A. Pre-Cochlear Implantation (*n*=81) B. Cochlear Implantation (*n*=81)	12, 16.8	SF-6D, HUI3	The mean utility using SF-6D was 0.575 (SD 0.056) before cochlear implantation, 0.59 (SD 0.064) 12 months after implantation, and the mean change was 0.015 (SD 0.082). The mean utility using HUI3 was 0.464 (SD 0.207) before implantation, 0.611 (SD 0.19) 16.8 months after implantation, and the mean utility change was 0.146 (SD (0.19).
Arnoldner et al. 2014 (2) [93]	Adult	Profound	North America	Observational, pre/post	A. Pre-Cochlear Implantation (*n*=32) B. Cochlear Implantation (*n*=32)	12, 120	SF-6D	The mean utility using SF-6D was 0.592 (uncertainty unclear) before cochlear implantation, 0.632 (uncertainty unclear) at 12 months post-implantation, and 0.632 (uncertainty unclear) 120 months after implantation.
Barton et al. 2006[69]	Pediatric	Moderate, Severe, Profound	Europe	Cross-sectional	A. Unclear (Average Hearing Loss, AHL, 40–70 dB, *n*=260; AHL 71–95 dB, *n*=464; AHL 96–106 dB, *n*=259; AHL > 105 dB, *n*=290) B. Cochlear Implantation (*n*=403)	N/A	HUI3	The treatment state was unclear for patients with moderate, profound, or severe hearing loss. The mean utility was 0.677, 95% CI [0.652, 0.702] for moderate hearing loss, 0.616, 95% CI [0.598, 0.634] for severe hearing loss, 0.497, 95% CI [0.469, 0.525] for profound hearing loss between 96–106 dB, and 0.353, 95% CI [0.327, 0.379] for profound hearing loss greater than 105 dB. The mean utility was 0.575, 95% CI [0.553, 0.598] for the cochlear implant group.
Bergman et al. 2020[44]	Adult	Profound	Europe	Observational, pre/post	A. Pre-Cochlear Implantation (*n*=16) B. Cochlear Implantation (*n*=22)	12, 36	HUI3	For men, the mean utility was 0.48 (SD 0.20) before cochlear implantation, and 0.69 (SD 0.16) one year after implantation, and 0.63 (SD 0.24) three years after implantation. For women, the mean utility was 0.43 (SD 0.24) before cochlear implantation, and 0.63 (SD 0.20) one year after implantation, and 0.59 (SD 0.18) three years after implantation.
Bichey et al. 2008[61]	Adult	Profound	North America	Cross-sectional‡	A. Pre-Cochlear Implantation (*n*=23) B. Unilateral Cochlear Implantation (*n*=23) C. Bilateral Cochlear Implantation (*n*=23)	Unclear	HUI3	The mean utility was 0.33 (SD 0.14) before cochlear implantation, 0.69 (SD 0.12) after the first implant, and 0.81 (SD 0.09) after the second implant. The mean change after the first implant was 0.11 (SD 0.06) and 0.48 (SD 0.16) after the second.
Briggs et al. 2001[94]	Adult	Profound	Australia/ New Zealand	Cross-sectional	A. Pre-Cochlear Implantation (*n*=54) B. Cochlear Implantation (*n*=148)	N/A	AQoL	The mean utility was 0.38 (SD 0.22) before implantation and 0.57 (SD 0.27) after implantation.
Chen et al. 2014[62]	Adult	Profound	Europe	Cross-sectional	A. Pre-Cochlear Implantation (*n*=90) B. Unilateral Cochlear Implantation (n=90) C. Bilateral Cochlear Implantation (*n*=90)	N/A	HUI3	The mean utility was 0.54 (uncertainty unclear) before cochlear implantation, 0.77 after the first implant, and 0.79 after the second implant.

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Table 4. (continued)

Reference	Population	Hearing Loss Severity	Setting	Study Design	Comparison	Follow-up Time (months)	Utility Instrument	Main Results
Cheng et al. 2000[70]	Pediatric	Profound	North America	Observational, pre/post	A. Pre-Cochlear Implantation (VAS, *n*=78; TTO, *n*=40; HUI3, *n*=22) B. Cochlear Implantation (VAS, *n*=78; TTO, *n*=40; HUI3, *n*=22)	22.8	VAS, TTO, HUI3	The mean utility using VAS was 0.59, 95% CI [0.53, 0.64] pre-cochlear implantation and 0.86, 95% CI [0.83, 0.89] after implantation. The mean change was 0.27, 95% CI [0.22, 0.32]. The mean utility using TTO was 0.75, 95% CI [0.67, 0.83] pre-cochlear implantation and 0.97, 95% CI [0.93, 0.1] after implantation. The mean change was 0.22, 95% CI [0.15, 0.28]. The mean utility using HUI3 was 0.25, 95% CI [0.16, 0.34] pre-cochlear implantation and 0.64, 95% CI [0.57, 0.70] after implantation. The mean change was 0.39, 95% CI [0.31, 0.46].
Clark et al. 2012[71]	Pediatric	Profound	North America	Observational, pre/post	A. Pre-Cochlear Implantation (*n*=188) B. Cochlear Implantation (*n*=178)	48	VAS	The mean utility was 88.3 (SD 12.5) before implantation. The mean change was stratified by age at implantation as follows: −1.0, 95% CI [−4.5, 2.6] for implanted <18 months of age; 5.7, 95% CI [1.5, 10] for implanted 18–36 months of age, and −1.8, 95% CI [−6.8, 3.2] for implanted >36 months of age.
Czerniejewska-Wolska et al. 2015[46]	Adult	Profound	Europe	Observational, pre/post	A. Pre-Cochlear Implantation (*n*=20) B. Cochlear Implantation (*n*=20)	12	HUI3	The mean utility was 0.38 (uncertainty unclear) before implantation and 0.50 (uncertainty unclear) after implantation.
Czerniejewska-Wolska et al. 2019[45]	Adult	Profound	Europe	Observational, pre/post	A. Pre-Cochlear Implantation (*n*=26) B. Cochlear Implantation (n=26)	12	HUI3	The mean utility was 0.494 (SD 0.249) before implantation and 0.564 (SD 0.207) after implantation.
Damen et al. 2007[47]	Adult	Profound	Europe	Observational, pre/post	A. Pre-Cochlear Implantation (group I, *n*=37; group II *n*=10; group III *n*=22) B. Cochlear Implants (group I, *n*=37; group II, *n*=10, group III, *n*=22)	48, 72, 120	HUI3	The mean utility for group I (cochlear implant users in 1998 and 2004) was 0.32 (SD 0.15) before implantation, 0.64 (SD 0.20) 48 months after implantation, and 0.57 (SD 0.22) 120 months after implantation. The mean utility for group II (non-implanted in 1998 and 2004) was 0.37 (SD 0.22) at baseline and 0.31 (SD 0.18) 72 months later. The mean utility for group III (non-implanted in 1998 and implanted between 1999 and 2004) was 0.38 (SD 0.21) before implantation, and 0.53 (SD (0.24) 72 months after implantation.
Francis et al. 2002[48]	Adult	Unclear	North America	Observational, pre/post	A. Pre-Cochlear Implantation (*n*=47) B. Cochlear Implantation (*n*=47)	31.2	HUI3	The mean utility was 0.37 (SD 0.26) before implantation, and 0.61 (SD 0.25) 31.2 months after implantation. The mean utility change was 0.24 (SD 0.33).
	Adult	Profound				3, 6	AQoL	

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Table 4. (continued)

Reference	Population	Hearing Loss Severity	Setting	Study Design	Comparison	Follow-up Time (months)	Utility Instrument	Main Results
Hawthorne et al. 2004[59]			Australia/ New Zealand	Observational, pre/post	A. Pre-Cochlear Implantation (mix of HA/no HA use, *n*=31) B. Cochlear Implants (*n*=31)			The mean utility was 0.36 (SD 0.23) before cochlear implantation, 0.50 (0.29) 3 months after implantation, and 0.64 (SD 0.28) 6 months after implantation.
Jianxin et al. 2017[72]	Pediatric	Profound	Asia	Observational, pre/post	A. Pre-Cochlear Implantation (*n*=29) B. Cochlear Implantation (*n*=29)	6, 12	VAS	The mean utility was 0.55, 95% CI [0.49, 0.61] before implantation, 0.77, 95% CI [0.73, 0.80] 6 months after implantation, and 0.81, 95% CI [0.77, 0.85] 12 months after implantation. The mean utility change from baseline to 6 months was 0.21, 95% CI [0.17, 0.26], and the mean utility change from baseline to 12 months was 0.26, 95% CI [0.19, 0.32].
Klop et al. 2008[58]	Adult	Profound	Europe	Observational, pre/post	A. Pre-Cochlear Implantation (*n*=44) B. Cochlear Implantation (n=44)	4, 12	TTO, HUI2	The mean utility using TTO was 0.63 (SD 0.25) before implantation, 0.85 (SD 0.18) 4 months after implantation, and 0.87 (SD 0.19) 12 months after implantation. The mean utility using HUI2 was 0.68 (SD 0.14) before implantation, 0.83 (SD 0.12) at 4 months, and 0.84 (SD 0.10) 12 months after implantation.
Krabbe et al. 2000[67]	Adult	Profound	Europe	Cross-sectional	A. Pre-Cochlear Implantation (control group, *n*=46, implantation group, *n*=45) B. Cochlear Implantation (*n*=45)	60	HUI2	The mean utility was 0.55 (SD 0.11) before implantation and 0.82 (SD 0.14) after implantation. The mean utility for the non-implanted control group (baseline) was 0.62 (SD 0.16). The mean change after implantation was 0.28 (SD 0.15).
Kuthubutheen et al. 2014[63]	Adult	Profound and Unclear	North America	Cross-sectional	A. Pre-Cochlear Implantation (*n*=30) B. Unilateral Cochlear Implantation (*n*=30) C. Bilateral Cochlear Implantation (*n*=30)	N/A	HUI3, EQ-5D, VAS, TTO	The mean utility using HUI3 was 0.54 before cochlear implantation, 0.77 after the first implant, and 0.79 after the second implant (variance unclear). The mean utility using EQ-5D was 0.79 before cochlear implantation, 0.89 after the first implant, and 0.92 after the second implant. The mean utility using VAS was 0.74 before cochlear implantation, 0.82 after the first implant, and 0.88 after the second implant. The mean utility using TTO was 0.63 before cochlear implantation, 0.80 after the first implant, and 0.93 after the second implant.
Lenarz et al. 2017[49]	Adult	Profound	Africa	Observational, pre/post	A. Pre-Cochlear Implantation (*n*=282) B. Cochlear Implantation (*n*=282)	12, 24, 36	HUI3	The mean utility was 0.457 (SE 0.015) before cochlear implantation, 0.606 (SE 0.018) 12 months after implantation, 0.60 (SE 0.022) 24 months after, and 0.54 (SE 0.038) 36 months after. The mean utility change was 0.149 (SE 0.018) from baseline to 12 months, 0.143 (SE 0.022) from baseline to 24 months, and 0.082 (SE 0.038) from baseline to 36 months.

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Table 4. (continued)

Reference	Population	Hearing Loss Severity	Setting	Study Design	Comparison	Follow-up Time (months)	Utility Instrument	Main Results
Liu et al. 2016[73]	Pediatric	Profound	Asia	Observational, pre/post	A. Pre-Cochlear Implantation (*n*=213) B. Cochlear Implantation (*n*=213)	12	HUI3	The mean utility was 0.671 before implantation and 0.915 at 12 months post-implantation. Uncertainty was unclear.
Lovett et al. 2019[74]	Pediatric	Profound	Europe	Cross-sectional	A. Unilateral Cochlear Implantation (VAS, *n*=20; HUI3, *n*=14) B. Bilateral Cochlear Implantation (VAS, *n*=30; HUI3, *n*=20)	N/A	VAS, HUI3	The mean utility using VAS was 0.90 (IQR 0.76–0.95) for unilateral cochlear implantation and 0.91 (IQR 0.85–1) for bilateral implantation. The mean utility using HUI3 was 0.78 (IQR 0.69–0.85) for unilateral cochlear implantation, and 0.83 (IQR 0.64–0.85) for bilateral implantation.
Muigg et al. 2020[60]	Adult	Profound	Europe	Observational, pre/post	A. Pre-Cochlear Implantation (*n*=20) B. Cochlear Implantation (*n*=20)	3, 6, 12, 24	HUI3	The mean utility was 0.57 (SD 0.18) before cochlear implantation, 0.61 (SD 0.27) 3 months after implantation, 0.72 (SD 0.17) 6 months after implantation, 0.71 (SD 0.18) 12 months after implantation, and 0.68 (SD 0.20) 24 months after implantation.
Müller et al. 2021[50]	Adult	Profound	Africa	Observational, pre/post	A. Pre-Cochlear Implantation (*n*=175) B. Cochlear Implantation (12 months *n*=137; 36 months, *n*=75)	12, 36	HUI3	The median utility was 0.437 (IQR 0.291) before cochlear implantation, and 0.691 (IQR 0.28) 36 months after implantation. The mean change at 12 months was 0.16, 95% CI [0.11, 0.21].
Palmer et al. 1999[51]	Adult	Profound	North America	Observational, pre/post	A. Pre-Cochlear Implantation (implant group, *n*=46; non-implant group, *n*=16) B. Cochlear Implantation (*n*=46)	6, 12	HUI3	The mean utility was 0.58 (SD 0.17) before implantation, 0.76 (SD 0.18) 6 months after, and 0.78 (SD 0.17) 12 months after. The mean utility for the non-implant comparison group was 0.58 (SD 0.20) at baseline, 0.57 (SD 0.18) at 6 months, and 0.58 (SD 0.23) at 12 months.
Ramakers et al. 2016[52]	Adult	Profound	Europe	Observational, pre/post	A. Pre-Cochlear Implantation (*n*=38) B. Cochlear Implantation (*n*=38)	12, 24	EQ-5D, HUI3, VAS	The median utility using EQ-5D was 1.00 (range: 0.61–1.00) before implantation, at both 12 (1.00; 0.65–1) and 24 (1.00; 0.3–1.00). month follow-up time points. The median utility using HUI3 was 0.55 (0.26–0.85) before implantation, 0.78 (0.22–0.85) 12 months after, and 0.77 (0.42–0.85). The median utility change using HUI3 was 0.17 (−0.25 to 0.51) after 12 months and 0.19 (−0.43 to 0.46) after 24 months. The median utility using VAS was 0.75 (0.55–1.00) before implantation, 0.80 (0.45–0.99) 12 months after implantation, and 0.80 (0.55 to 1.00) 24 months after. The median utility change using VAS was 0.05 (−0.25 to 0.54) after 12 months and 0.04 (−0.29 to 0.56) after 24 months.
Runge et al. 2016[53]	Adult	Profound	Europe	Observational, pre/post	A. Pre-Cochlear Implantation (*n*=38)	6, 12	HUI3	The mean utility was 0.45 (SE 0.033) before implantation, 0.63 (SE 0.038) 6 months after, and 0.60 (SE 0.031) 12 months after.

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Table 4. (continued)

Reference	Population	Hearing Loss Severity	Setting	Study Design	Comparison	Follow-up Time (months)	Utility Instrument	Main Results
					B. Cochlear Implantation (*n*=38)			
Sach et al. 2007[75]	Pediatric	Profound	Europe	Cross-sectional‡	A. Pre-Cochlear Implantation (*n*=221) B. Cochlear Implantation (*n*=221)	42	VAS, EQ-5D	The mean utility change using VAS was 0.14, 95% CI [0.1, 0.18].
Sarant et al. 2019[57]	Adult	Profound	Australia/ New Zealand	Observational, pre/post	A. Pre-Cochlear Implantation (mix of HA/no HA use; *n*=20) B. Cochlear Implantation (*n*=20)	18	HUI3	The mean utility before implantation was 0.56 (uncertainty unclear) and 0.67 (uncertainty unclear) 18 months post-implantation.
Semenov et al. 2013[77]	Pediatric	Profound	North America	Observational, pre/post	A. Pre-Cochlear Implantation (implanted <18 months, *n*=60; 18–36 months, *n*=71; >36 months, *n*=44) B. Cochlear Implantation (implanted <18 months, *n*=60; 18–36 months, *n*=71; >36 months, *n*=44)	72	HUI3	The mean utility for infants implanted <18 months was 0.26 (SD 0.14) before implantation and 0.76 (SD 0.14) 6 years after implantation. The mean change was 0.51 (SD 0.21). The mean utility for infants implanted between 18 and 36 months was 0.31 (0.17) before implantation and 0.72 (SD 0.20) 6 years after implantation. The mean change was 0.41 (SD 0.24). The mean utility for infants implanted >36 months was 0.37 (SD 0.21) before implantation and 0.71 (SD 0.17) 6 years after implantation. The mean change was 0.34 (SD 0.24).
Sladen et al. 2017[54]	Adult	Profound	North America	Observational, pre/post	A. Pre-Cochlear Implantation (*n*=21) B. Cochlear Implantation (*n*=21)	6, 12	HUI3	The mean utility using HUI3 was 0.4998 (SD 0.2138) before implantation, 0.611 (SD 0.22) 6 months after, and 0.5297 (SD 0.2309) 12 months after.
Smith-Olinde et al. 2008[36]	Pediatric	Moderate, Profound	North America	Cross-sectional	A. Hearing Aid (PTA 42.6, *n*=22; PTA 58.3, *n*=34; PTA 83.4, *n*=19) B. Cochlear Implantation (PTA 95.6, *n*=28)	N/A	HUI3, QWB	The mean HUI3-estimated utility for persons using hearing aids was 0.707 (SD 0.18) for the group with PTA 42.6, 0.615 (SD 0.22) for the group with PTA 58.3, and 0.54 (SD 0.22) for the group with PTA 83.4. For persons using a cochlear implant (PTA 95.6) the utility was 0.609 (SD 0.16). The mean QWB-estimated utility for persons using hearing aids was 0.645 (SD 0.12) for the group with PTA 42.6, 0.589 (SD 0.11) for the group with PTA 58.3, and 0.551 (SD 0.07) for the group with PTA 83.4. For persons using a cochlear implant (PTA 95.6) the utility was 0.613 (SD 0.09).
Smulders et al. 2016[55]	Adult	Profound	Europe	Observational, pre/post	A. Pre-Cochlear Implantation (*n*=19) B. Unilateral Cochlear Implantation (*n*=19) C. Bilateral Cochlear Implantation (*n*=19)	12, 24	HUI3, EQ-5D, TTO, VAS	For the unilateral implant group, the mean utility using HUI3 was 0.58 before cochlear implantation, and 0.68 at both 12- and 24-months post-implantation. For the bilateral implant group, the mean utility using HUI3 was 0.56 before implantation, 0.71 at 12 months post-implantation, and 0.72 at 24 months post-implantation.

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Table 4. (continued)

Reference	Population	Hearing Loss Severity	Setting	Study Design	Comparison	Follow-up Time (months)	Utility Instrument	Main Results
								For the unilateral implant group, the mean utility using EQ-5D was 0.95 before cochlear implantation, 0.93 at 12 months post-implantation, and 0.94 at 24 months post-implantation. For the bilateral implant group, the mean utility using EQ-5D was 0.93 before implantation, 0.90 at 12 months post-implantation, and 0.92 at 24 months post-implantation. For the unilateral implant group, the mean utility using TTO was 0.91 at 12 months post-implantation, and 0.90 at 24 months post-implantation. For the bilateral implant group, the mean utility using TTO was 0.99 at both 12- and 24-months post--implantation. Pre-implantation TTO utility scores were not generated. For the unilateral implant group, the mean utility using VAS was 0.66 before cochlear implantation, and 0.79 at 12 months post-implantation, and 0.80 at 24 months post-implantation. For the bilateral implant group, the mean utility using VAS was 0.72 before implantation, 0.75 at 12 months post-implantation, and 0.78 at 24 months post-implantation.
Sparreboom et al. 2012[76]	Pediatric	Profound	Europe	Observational, pre/post	A. Pre-Op Before Second Cochlear Implantation (VAS, *n*=30; HUI3, *n*=22; PedsQL, *n*=30) B. Unilateral Cochlear Implantation, never receive second implant (VAS, *n*=9; HUI3, *n*=8; PedsQL, *n*=9) C. Bilateral Cochlear Implantation (VAS, *n*=30; HUI3, *n*=22; 12-month PedsQL, *n*=29; 24-month PedsQL, n=30)	12, 24	VAS, HUI3, PedsQL,	The median utility using VAS was 0.9 (IQR 0.80–0.95) before second implant, 0.9 (IQR 0.8–0.97) 12 months after second implant, and 0.9 (IQR 0.8–0.96) 24 months after. The mean utility using VAS was 1.0 (IQR 0.9–1.0) for the unilateral implant group at both 12- and 24-months post-implantation. The median utility using HUI3 was 0.58 (IQR 0.53–0.78) before second implant, 0.66 (IQR 0.53–0.78) 12 months after second implant and 0.76 (IQR 0.57–0.89) 24 months after. The mean utility using HUI3 for the unilateral implant group was 0.71 (IQR 0.58–0.78) at the first QoL assessment and 0.71 (IQR 0.62–0.82) a year later at the second QoL assessment. The median utility using PedsQL was 0.84 (IQR 0.79–0.89) before second implant, 0.81 (IQR 0.72–0.90) 12 months after second implant, and 0.82 (IQR 0.67–0.89) 24 months after. The mean utility using PedsQL for the unilateral implant group was 0.88 (IQR 0.69–0.94) at the first QoL assessment and 0.84 (IQR 0.69–0.94) a year later at the second QoL assessment.

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Table 4. (continued)

Reference	Population	Hearing Loss Severity	Setting	Study Design	Comparison	Follow-up Time (months)	Utility Instrument	Main Results
Summerfield et al. 2002[29]	Adult	Profound	Europe	Observational, pre/post	A. Untreated (n=87) B. Hearing Aids (*n*=115) C. Cochlear Implantation (traditional candidate, *n*=87; marginal hearing aid user, *n*=115)	6	HUI3	The mean utility was 0.562, 95% CI [0.527, 0.596] before cochlear implantation (untreated), and 0.75, 95% CI [0.705, 0.794] after implantation. The mean utility change was 0.188, 95% CI [0.15, 0.226] for traditional cochlear implant users. The mean utility was 0.725, 95% CI [0.693, 0.757] with hearing aids, and 0.802, 95% CI [0.767, 0.838] after implantation. The mean utility change after cochlear implantation was 0.077, 95% CI [0.045, 0.11] for those attaining some benefit from HAs.
Summerfield et al. 2006[80]	Adult	Profound	Europe	Observational, pre/post (within group)†	A. Three months after Bilateral Cochlear Implantation (*n*=24) B. Nine months after Bilateral Cochlear Implantation (*n*=24)	3, 9	HUI3, VAS, EQ-5D	The mean utility change using HUI3 was −0.027, 95% CI [−0.107, 0.053] 3 months after second implantation and −0.020, 95% CI [−0.107, 0.067] 9 months after. The mean utility change using VAS was −3.56, 95% CI [−10.22, 3.56] 3 months after second implantation and −4.89, 95% CI −11.56, 2.67] 9 months after. The mean utility change using EQ-5D was −0.068, 95% CI [−0.164, 0.029] 3 months after second implantation and −0.071, 95% CI [−0.129, −0.007] 9 months after.
Theriou et al. 2019[65]	Adult	Profound	Europe	Cross-sectional	A. Bimodal (*n*=31) C. Cochlear Implantation (*n*=60)	N/A	HUI3	The mean utility for bimodal stimulation was 0.51, 95% CI [0.428, 0.592]. The mean for cochlear implantation alone was 0.478, 95% CI [0.42, 0.536].
UK Cochlear Implant Study Group, 2004[42]	Adult	Profound	Europe	Observational, pre/post	A. Pre-Cochlear Implantation (*n*=311) B. Cochlear Implantation (*n*=311)	3, 9	HUI3	The mean utility before cochlear implantation (*n*=311) was 0.433, 95% CI [0.411, 0.455]. Three months after implantation (*n*=311) the mean utility was 0.611, 95% CI [0.587, 0.634] and nine months after implantation the mean was 0.63, 95% CI [0.608, 0.652]. The mean utility change between pre-implant to nine months was 0.197, 95% CI [0.176, 0.218].
van Zon et al. 2017[81]	Adult	Profound	Europe	Randomized controlled trial	A. Unilateral Cochlear Implantation (*n*=18) B. Bilateral Cochlear Implantation (*n*=19)	24	VAS, TTO, EQ-5D, HUI3	The median utility using VAS was 80 (Range: 65–100) for unilateral cochlear implantation and 80 (Range: 55–95) for bilateral cochlear implantation. The median utility using TTO was 100 (Range: 50–100) for unilateral cochlear implantation and 100 (Range: 85–100) for bilateral cochlear implantation. The median utility using EQ-5D was 1.0 (Range: 0.8–1.0) for unilateral cochlear implantation and 1.0 (Range: 0.7–1.0) for bilateral cochlear implantation. The median utility using HUI3 was 0.7 (Range: 0.4–0.9) for unilateral cochlear

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Table 4. (continued)

Reference	Population	Hearing Loss Severity	Setting	Study Design	Comparison	Follow-up Time (months)	Utility Instrument	Main Results
								implantation and 0.8 (Range: 0.5–0.9) for bilateral cochlear implantation.
Wyatt et al. 2019[66]	Adult	Profound	North America	Cross-sectional	A. Pre-Cochlear Implantation (n=32) C. Cochlear Implantation (n=229)	N/A	HUI3	The mean utility for the pre-implantation state was 0.589, 95% CI [0.519, 0.7]. The mean for cochlear implantation was 0.793, 95% CI [0.773, 0.813].
Zwolan et al. 2014[56]	Adult	Profound	North America	Observational, pre/post	A. Pre-Cochlear Implantation, (<65 years, n=20; ≥65 years, n=18) C. Cochlear Implantation (<65 years, n=20; ≥65 years, n=18)	6, 12	HUI3	The mean utility for the group <65 years was 0.475, 95% CI [0.285, 0.666] before implantation, 0.698, 95% CI [0.292, 0.872] 6 months after implantation, and 0.633, 95% CI [0.459, 0.797] 12 months after implantation. The mean utility for the group ≥65 years was 0.433, 95% CI [0.226, 0.626] before implantation, 0.548, 95% CI [0.298, 0.8] 6 months after implantation, and 0.551, 95% CI [0.338, 0.767] 12 months after implantation.
Bimodal Stimulation								
Buchman et al. 2020[78]	Adult	Profound	North America	Observational, pre/post	A. Hearing Aids (n=96) B. Bimodal Stimulation (n=96)	6	HUI3	The mean utility at baseline using hearing aids was 0.46, 95% CI [0.42, 0.50]. The mean utility after bimodal stimulation was 0.64, 95% CI [0.60, 0.68] and the mean utility change was 0.18, 95% CI [0.14, 0.22].
Sanhueza et al. 2019[64]	Adult	Severe, Profound	Europe	Cross-sectional	A. Bimodal Stimulation (n=31) B. Cochlear Implantation (n=30)	N/A	HUI2, HUI3	The mean utility using HUI2 was 0.789 (SE 0.067) for the bimodal group (patient stimulated with a hearing aid and cochlear implant) and, 0.809 (SE 0.056) for the cochlear implant group. The mean utility using HUI3 was 0.591 (SE 0.103) for the bimodal group, and 0.619 (SE 0.079) for the cochlear implant group.
Wick et al. 2020[79]	Adult	Severe	North America	Observational, pre/post	A. Hearing Aids (n=70) B. Bimodal Stimulation (n=70)	6	HUI3	The mean utility at baseline using hearing aids alone was 0.428, 95% CI [0.379, 0.478]. The mean utility was 0.614, 95% CI [0.564, 0.663] 6 months after bimodal stimulation. The mean utility change was 0.186, 95% CI [0.136, 0.234].

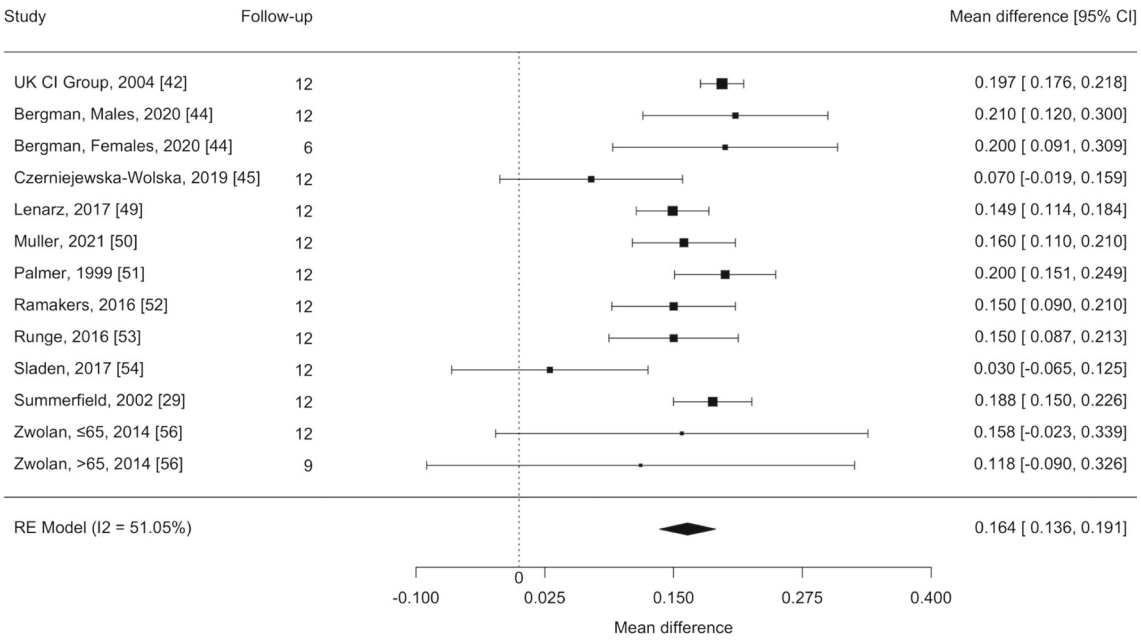
Abbreviations: AQoL Assessment of Quality of Life, BEPTA better-ear pure tone average, CI Confidence Interval, dB decibel, EQ-5D EuroQol-5 Dimension, HUI2 Health Utilities Index 2, HUI3 Health Utilities Index 3, IQR interquartile range, N/A not applicable, PedsQL Pediatric Quality of Life Inventory, PTA pure tone average, QWB Quality Wellbeing Scale, SD standard deviation, SE standard error, SF-6D Short-Form Six-Dimension, TTO time trade-off, VAS visual analog scale

**One study that used the EQ-5D-5L to measure the QoL of persons with cochlear implants had an unclear study design, unclear population sizes, and unclear variance. As such we were unable to include this study in the table.*

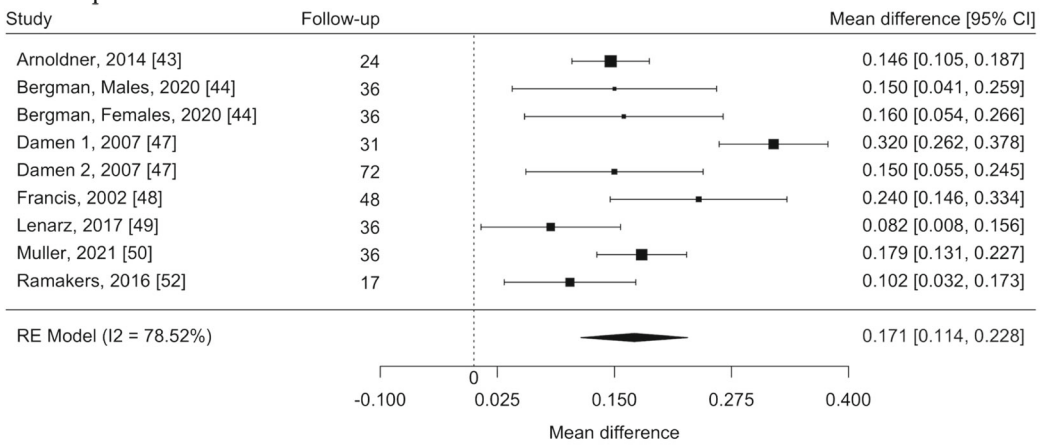
†This is a randomized controlled trial that had a waitlist for second cochlear implantation. We extracted data for the within group changes to facilitate data synthesis.

‡These studies were categorized as cross-sectional because they used a single survey to ask participants retrospectively about their quality of life before and after cochlear implantation.

A Adult cochlear implantation compared to pre-implantation measured by HUI-3, ≤12 months of follow-up.



B Adult cochlear implantation compared to pre-implantation measured by HUI3, >12 months of follow-up.



C Pediatric cochlear implantation compared to pre-implantation measured by VAS.

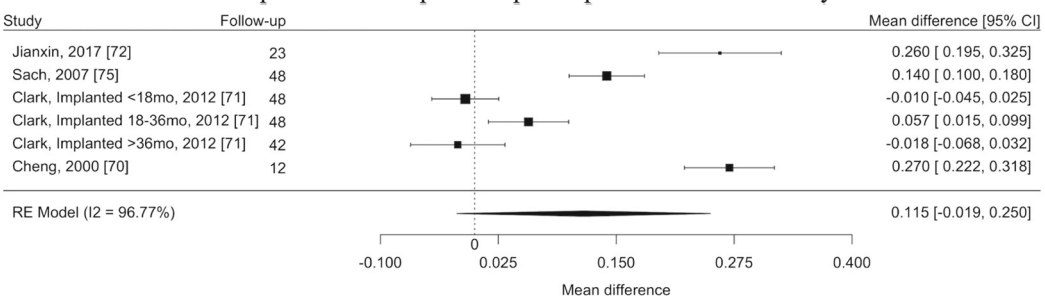


Figure 3 Cochlear implant meta-analyses. The figure shows the forest plots for meta-analyses of mean change scores for (A) adult cochlear implantation compared to pre-implantation measured by HUI3, ≤12 months of follow-up; (B) adult cochlear implantation compared to pre-implantation measured by HUI3, >12 months of follow-up; and (C) pediatric cochlear implantation compared to pre-implantation measured by VAS. Estimates to the right of the x-axis show a positive utility increase after intervention. CI, confidence interval; mo, month; RE, random effects.

Several pre/post studies used different measures in the same population and intervention and found different results based on the utility elicitation method used. One study included in the HUI3 meta-analysis also reported a non-significant pre/

post-cochlear implantation change score using the SF-6D of 0.02 (SE=0.01), despite showing significant differences using the HUI3 (mean change=0.15, SE=0.02).[43] Another pre/post study compared unilateral cochlear implantation to the pre-cochlear implantation health state using VAS, finding median changes of 0.05 (range: −0.25 to 0.54) and 0.04 (range: −0.29 to 0.56) at 12 and 24 months, but found no change when using the EQ-5D.[52]

Two other pre/post studies compared unilateral cochlear implantation to pre-implantation states using the EQ-5D, both finding non-significant changes.[52, 55] Time trade-off methods were used in one pre/post study, revealing a mean change of 0.24 over 12 months.[58] Other utility elicitation measures included the AQoL and HUI2 (Appendix 8).[58, 59] One study included patients with unilateral hearing loss and found post-cochlear implant HUI3-estimated utility increment of 0.11 at 2 years.[60] Additionally, eight studies assessed QoL in cochlear implantation with a cross-sectional design and without a comparison group (Appendix 8).[61–68]

Pediatric Cochlear Implantation

We identified ten studies that estimated the QoL utility for pediatric cochlear implantation (Table 4).[36, 69–77] Four studies used the VAS to compare pediatric cochlear implantation to pre-implantation states, and the synthesized QoL utility change was 0.12; however, the 95% confidence interval included no treatment effect (Appendix 7, Fig. 3C; 95% CI: −0.02 to 0.25).[70–72, 75] One high-quality study included in the meta-analysis found non-significant effects of cochlear implantation on parent-reported utility measured by VAS; however, the study did find significant parent-reported VAS improvement in child development.[71] In this study, hearing and language gains were more strongly associated with parent-reported VAS development and, for parents, utility may be more closely associated with enhanced communication capacity. However, we included this study in the meta-analysis given its high quality and felt it was important to emphasize any potential reduction in significant utility change. Please see Appendix 9 for a sensitivity analysis with this study removed (VAS-measured QoL utility change of 0.22; 95% CI: 0.04 to 0.40).

Five studies[36, 69, 70, 73, 77] used the HUI3 to compare unilateral cochlear implantation to pre-implantation in children with profound hearing loss, with three pre/post studies[70, 73, 77] finding significant utility increments vs. the untreated state. Two studies found increasing utility increments with earlier age of implantation.[69, 77] One study used VAS, HUI3, and TTO to assess pre/post-cochlear implantation in the same population and found significant increments vs. the pre-implantation state.[70] Three studies assessed pediatric cochlear implantation utility with a cross-sectional design without comparison (Appendix 8).[36, 69, 75]

Adult Bimodal Stimulation

Two studies in North America compared bimodal stimulation (cochlear implant + contralateral hearing aid) to hearing aids alone in patients with severe-to-profound bilateral hearing loss using the HUI3 (Table 4).[78, 79] Two other studies assessed bimodal stimulation using a cross-sectional design without comparison (Appendix 8).[64, 65]

Adult Bilateral Cochlear Implantation

Six studies evaluated bilateral cochlear implantation in adults, including three cross-sectional studies[55, 61–63] and three RCTs (Table 4).[55, 80, 81] While all three RCTs found no impact of bilateral compared to unilateral cochlear implantation in adults on QoL utility, two RCTs found improvements in hearing-related outcomes.[55, 80, 81]

Pediatric Bilateral Cochlear Implantation

Two studies, one cross-sectional[74] and one pre-post[76], comparing sequential bilateral cochlear implantation to unilateral cochlear implantation in children with profound hearing loss found no significant utility difference for the second implant (Table 4).[74, 76]

DISCUSSION

This systematic review found evidence of benefits of hearing healthcare interventions on patient QoL utility. Our meta-analysis revealed that acoustic hearing aids increased mean utility by 0.11 in adults with mild-to-moderate hearing loss, implantable hearing aids in adults increased mean utility by 0.07, and cochlear implants in adults increased mean utility by 0.16 to 0.17. In the meta-analysis of pediatric cochlear implantation, the 95% CI for the change in VAS measures included no effect, likely due to a single study showing no effect at 4 years post-implantation.[71] We additionally identified studies describing bilateral cochlear implantation, which showed little to no incremental benefit compared to unilateral cochlear implantation, and bimodal stimulation (hearing aid + cochlear implant), which did show benefit compared to hearing aids alone. The quality scores of included studies were most frequently deducted for lack of reporting on missingness of data and/or small sample sizes.

Nearly all included studies were observational, and many had a pre/post intervention design. This study design may bias findings due to selection bias. We identified four RCTs, a design that minimizes potential for bias. One reported significant effects of hearing aids compared to no treatment.[22] The other three found no significant differences in QoL for bilateral compared to unilateral cochlear implantation.[55, 80, 81] While RCTs provide the highest quality evidence on the treatment effects of hearing healthcare, there may not be equipoise to conduct an RCT comparing hearing interventions (hearing aid or cochlear implant) to no treatment because

studies have consistently shown hearing-specific and quality of life benefits of hearing aids and cochlear implants.[3, 82–84]

Consistent with prior literature, our results also showed a difference in QoL utility for hearing healthcare interventions based on the measure used to elicit utility.[43] In general, the HUI3, HUI2, VAS, and TTO showed significant improvements after treatment. However, commonly used metrics (EQ-5D and SF-6D) showed little to no benefit. This suggests that the EQ-5D and SF-6D do not adequately detect benefits related to hearing and communication, especially considering several studies used multiple measures in the same patients and found disparate results between measures.[23–26, 43, 52, 55, 80, 81] Future cost-effectiveness and other economic studies of hearing healthcare might incorporate HUI, VAS, or TTO utility estimates, while recognizing all utilities are patient-specific and have a range of uncertainty to be explored.

Our results help clarify the impact of hearing healthcare for policy development. The mean change scores for current interventions in hearing healthcare may be used as inputs for effectiveness in economic analyses. Previous economic analyses have used varying utility benefits of hearing healthcare, and some assume that hearing treatment improves DALY health state by one hearing severity level.[27, 28, 85] In analyses making this assumption, such as those by the Global Burden of Disease and World Health Organization, hearing aids would impart a DALY benefit of 0.01–0.065 for persons with mild-to-moderate hearing loss, which is lower than our findings of a utility benefit of 0.11.[1, 27, 28] This increase in the HUI3-estimated utility is well above published estimates of the minimum clinically important difference (0.03).[86] Incorporation of a larger utility benefit would improve the cost-effectiveness of hearing interventions and support more investment for hearing interventions.

While our results show that treatment of hearing loss has clear benefits on QoL utility, access remains low.[1, 87–89] Further, earlier intervention in both children and adults is associated with improved hearing outcomes, which also emphasizes the importance of timely hearing care.[69, 77, 90] Cost remains a significant barrier to treatment of hearing loss access for individuals with hearing loss, with many countries having limited insurance or governmental coverage of costly hearing aids, thus restricting access.[1] Innovative policies, such as the recent US Food and Drug Administration Reauthorization act allowing for over-the-counter hearing aids for mild-to-moderate hearing loss, might help to reduce costs of devices beneficial to health.

Our review identified several actionable areas for further research, including the need for high-quality estimates of the utility of untreated hearing loss. We identified two studies using DCE methods to estimate the DALY effects of untreated hearing loss for use in the Global Burden of Disease studies.[27, 28] However, the DALY effects measured in these studies may not be compatible with treatment effects estimated by other measures, such as the HUI3. Additionally, the impact of bilateral cochlear implantation compared to unilateral implantation on QoL utility remains unclear even though there are well-established benefits in hearing-related outcomes.[91, 92] We were also unable to identify any studies reporting the effects of pediatric acoustic hearing aids on QoL utility. Further, there were few analyses conducted in low- and middle-income countries, so future research should investigate the QoL utility effects of treatment of hearing loss in these settings.

This study has several limitations. First, included studies were heterogeneous in their study designs, populations, interventions, QoL measures, and outcomes. However, we combined sufficiently similar studies using meta-analysis and qualitatively described studies not suitable for meta-analysis. Further, we discussed potential study characteristics associated with differing outcomes. Second, there are several health status measures that may be translated into utility values through mapping equations, such as the 36-item Short-Form Survey; but, we did not include such studies as the mapping equations often require unpublished patient-level data.

This systematic review found evidence that treatments of hearing loss have a beneficial impact on patient-reported QoL utility. In meta-analysis, hearing aids, unilateral cochlear implants, and implantable hearing aids all improved QoL utility. Future research could be carried out to clarify the QoL utility of untreated hearing loss, pediatric hearing aids and cochlear implants, bilateral cochlear implants, and impacts in low- and middle-income countries. Given the improvement in patient-reported QoL following treatment, increasing provision of and access to hearing healthcare is warranted.

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Author Contribution *EDB, KK, OO, and GDS conceived the study. EDB, KK, NF, GZ, MKH, OO, and GDS screened articles for inclusion and extracted data. ASK provided statistical expertise. EDB, ASK, and GDS performed the meta-analysis. All authors contributed to data interpretation. EDB, KK, NF, AA, and GDS wrote the first draft of the manuscript. All authors critically reviewed the manuscript for intellectual content.*

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Declarations:

Data Sharing: *The data and analyses may be requested from the corresponding author.*

Conflict of Interest: *SDE reports an honorarium from HearX for speaking on Viewpoint. All other authors have no conflicts of interest related to this work.*

REFERENCES

1. World Health Organization. World Report on Hearing. 2021. Accessed 11 October 2021 at https://www.who.int/teams/noncommunicable-diseases/sensory-functions-disability-and-rehabilitation/highlighting-priorities-for-ear-and-hearing-care.
2. **Wilson BS, Tucci DL, Merson MH, O'Donoghue GM.** Global hearing health care: new findings and perspectives. Lancet 2017; **390**(10111): 2503-15.
3. **Ferguson MA, Kitterick PT, Chong LY, Edmondson-Jones M, Barker F, Hoare DJ.** Hearing aids for mild to moderate hearing loss in adults. Cochrane Database Syst Rev. 2017; (9).
4. **Yueh B, Collins MP, Souza PE, et al.** Long-term effectiveness of screening for hearing loss: the screening for auditory impairment–which hearing assessment test (SAI-WHAT) randomized trial. J Am Geriatr Soc. 2010; **58**(3): 427-34.
5. **Zoratti MJ, Pickard AS, Stalmeier PFM, Ollendorf D, Lloyd A, Chan KKW, Husereau D, Brazier JE, Krahn M, Levine M, Thabane L, Xie F; Health Utility Book (HUB) Working Group.** Evaluating the conduct and application of health utility studies: a review of critical appraisal tools and reporting checklists. Eur J Health Econ. 2021; **22**(5): 723-33. https://doi.org/10.1007/s10198-021-01286-0.
6. **Johnson FR, Scott FI, Reed SD, Lewis JD, Bewtra M.** Comparing the noncomparable: the need for equivalence measures that make sense in health-economic evaluations. Value Health. 2019; **22**(6): 684-92.
7. **Adamiak G.** Methods for the economic evaluation of health care programmes, 3rd ed. J Epidemiol Community Health. 2006; **60**(9): 822-3.
8. **Neumann PJ, Sanders GD, Russell LB, Siegel JE, Ganiats TG (eds).** Cost-effectiveness in health and medicine, 2nd edn (New York, 2016; online edn, Oxford Academic, 17 Nov. 2016). https://doi.org/10.1093/acprof:oso/9780190492939.001.0001.
9. **Payakachat N, Murawski MM, Summers KH.** Health utility and economic analysis: theoretical and practical issues. Expert Rev Pharmacoecon Outcomes Res. 2009; **9**(4): 289-92. https://doi.org/10.1586/erp.09.36.
10. **Brazier J, Deverill M, Green C.** A review of the use of health status measures in economic evaluation. J Health Serv Res Policy. 1999; **4**(3): 174-84.
11. **Hutton B, Salanti G, Caldwell DM, et al.** The PRISMA extension statement for reporting of systematic reviews incorporating network meta-analyses of health care interventions: checklist and explanations. Ann Intern Med. 2015; **162**(11): 777-84.
12. **Wilson BS, Tucci DL, O'Donoghue GM, Merson MH, Frankish H.** A Lancet Commission to address the global burden of hearing loss. Lancet. 2019; **393**(10186): 2106-8.
13. World report on hearing. Geneva: World Health Organization; 2021. Licence: CC BY-NC-SA 3.0 IGO.
14. **Papaioannou, D., Brazier, J.E., Paisley, S.** (2011) NICE DSU Technical Support Document 9: The identification, review and synthesis of health state utility values from the literature. Accessed 14 October 2021 at http://www.nicedsu.org.uk.
15. **Szabo SM, Audhya IF, Malone DC, Feeny D, Gooch KL.** Characterizing health state utilities associated with Duchenne muscular dystrophy: a systematic review. Qual Life Res. 2020; **29**(3): 593-605.
16. **Meregaglia M, Cairns J.** A systematic literature review of health state utility values in head and neck cancer. Health Qual Life Outcomes. 2017; **15**(1): 174.
17. **Wan X, Wang W, Liu J, Tong T.** Estimating the sample mean and standard deviation from the sample size, median, range and/or interquartile range. BMC Med Res Methodol. 2014; **14**(1): 1-13.
18. **Knapp G, Hartung J.** Improved tests for a random effects meta-regression with a single covariate. Stat Med. 2003; **22**(17): 2693-710.
19. **Langan D, Higgins JPT, Jackson D, et al.** A comparison of heterogeneity variance estimators in simulated random-effects meta-analyses. Res Synth Methods. 2019; **10**(1): 83-98.
20. **Barton GR, Bankart J, Davis AC.** A comparison of the quality of life of hearing-impaired people as estimated by three different utility measures. Int J Audiol. 2005; **44**(3): 157-63.
21. **Joore M, Brunenberg D, Zank H, et al.** Development of a questionnaire to measure hearing-related health state preferences framed in an overall health perspective. Int J Technol Assess Health Care. 2002; **18**(3): 528-39.
22. **Kaur P, Chong S, Kannapiran P, et al.** Cost-utility analysis of hearing aid device for older adults in the community: a delayed start study. BMC Health Serv Res. 2020; **20**(1112): 1-11.
23. **Vuorialho A, Karinen P, Sorri M.** Effect of hearing aids on hearing disability and quality of life in the elderly. Int J Audiol. 2006; **45**(7): 400-5.
24. **Vuorialho A, Karinen P, Sorri M.** Counselling of hearing aid users is highly cost-effective. Eur Arch Otorhinolaryngol. 2006; **263**(11): 988-95.
25. **Davis A, Smith P, Ferguson M, Stephens D, Gianopoulos I.** Acceptability, benefit and costs of early screening for hearing disability: a study of potential screening tests and models. Health Technol Assess. 2007; **11**(42): 1-294.
26. **Grutters JP, Joore MA, van der Horst F, Verschuure H, Dreschler WA, Anteunis LJ.** Choosing between measures: comparison of EQ-5D, HUI2 and HUI3 in persons with hearing complaints. Qual Life Res. 2007; **16**(8): 1439-49.
27. **Salomon JA, Haagsma JA, Davis A, et al.** Disability weights for the Global Burden of Disease 2013 study. Lancet Glob Health. 2015; **3**(11): e712-23.
28. **Salomon JA, Vos T, Hogan DR, et al.** Common values in assessing health outcomes from disease and injury: disability weights measurement study for the Global Burden of Disease Study 2010. Lancet (British edition). 2012; **380**(9859): 2129-43.
29. **Summerfield AQ, Marshall DH, Barton GR, Bloor KE.** A cost-utility scenario analysis of bilateral cochlear implantation. Arch Otolaryngol Head Neck Surg. 2002; **128**(11): 1255-62.
30. **Petrou S, McCann D, Law CM, Watkin PM, Worsfold S, Kennedy CR.** Health status and health-related quality of life preference-based outcomes of children who are aged 7 to 9 years and have bilateral permanent childhood hearing impairment. Pediatrics. 2007; **120**(5): 1044-52.
31. **Baek MK, Kim YS, Kim EY, Kim AJ, Choi WJ.** Health-related quality of life in Korean adults with hearing impairment: the Korea National Health and Nutrition Examination Survey 2010 to 2012. PLoS One. 2016; **11**(10): e0163999.
32. **Kwon OD, Jung SY, Park HY, Peak SK, Cho SH, Cho SJ.** Comparison of the marginal utility and disease burden of hearing loss and other chronic diseases. Korean J Fam Med 2018; **39**(6): 364-9.
33. **Joore MA, Van Der Stel H, Peters HJ, Boas GM, Anteunis LJ.** The cost-effectiveness of hearing-aid fitting in the Netherlands. Arch Otolaryngol Head Neck Surg. 2003; **129**(3): 297-304.
34. **Turunen-Taheri S, Skagerstrand Å, Hellström S, Carlsson PI.** Patients with severe-to-profound hearing impairment and simultaneous severe vision impairment: a quality-of-life study. Acta Otolaryngol. 2017; **137**(3): 279-85.
35. **Le HND, Petersen S, Mensah F, Gold L, Wake M, Reilly S.** Health-related quality of life in children with low language or congenital hearing loss, as measured by the PedsQL and Health Utility Index Mark 3. Value Health. 2020; **23**(2): 164-70.
36. **Smith-Olinde L, Grosse SD, Olinde F, Martin PF, Tilford JM.** Health state preference scores for children with permanent childhood hearing loss: a comparative analysis of the QWB and HUI3. Qual Life Res. 2008; **17**(6): 943-53.
37. **den Besten CA, Monksfield P, Bosman A, et al.** Audiological and clinical outcomes of a transcutaneous bone conduction hearing implant: Six-month results from a multicentre study. Clin Otolaryngol. 2019; **44**(2): 144-57.
38. **Edfeldt L, Strömbäck K, Grendin J, et al.** Evaluation of cost-utility in middle ear implantation in the 'Nordic School': a multicenter study in Sweden and Norway. Acta Otolaryngol. 2014; **134**(1): 19-25.
39. **Hol MK, Spath MA, Krabbe PF, et al.** The bone-anchored hearing aid: quality-of-life assessment. Arch Otolaryngol Head Neck Surg. 2004; **130**(4): 394-9.
40. **Monksfield P, Jowett S, Reid A, Proops D.** Cost-effectiveness analysis of the bone-anchored hearing device. Otol Neurotol. 2011; **32**(8): 1192-7.
41. **de Wolf MJ, Hol MK, Mylanus EA, Snik AF, Cremers CW.** Benefit and quality of life after bone-anchored hearing aid fitting in children with unilateral or bilateral hearing impairment. Arch Otolaryngol Head Neck Surg. 2011; **137**(2): 130-8.
42. **Summerfield Q.** Criteria of candidacy for unilateral cochlear implantation is postlingually defeaned adults II: Cost-effectiveness analysis. Ear Hear. 2004; **25**(4): 336-60.
43. **Arnoldner C, Lin VY, Bresler R, et al.** Quality of life in cochlear implantees: comparing utility values obtained through the Medical Outcome Study Short-Form Survey-6D and the Health Utility Index Mark 3. Laryngoscope. 2014; **124**(11): 2586-90.
44. **Bergman P, Lyxell B, Harder H, Mäki-Torkko E.** The outcome of unilateral cochlear implantation in adults: speech recognition, health-related quality of life and level of anxiety and depression: a one- and three-year follow-up study. Int Arch Otorhinolaryngol. 2020; **24**(3): e338-46.
45. **Czerniejewska-Wolska H, Kałos M, Gawłowska M, et al.** Evaluation of quality of life in patients after cochlear implantation surgery in 2014-2017. Otolaryngol Pol. 2019; **73**(2): 11-7.
46. **Czerniejewska-Wolska H, Kałos M, Sekula A, et al.** Quality of life and hearing after cochlear implant placement in patients over 60 years of age. Otolaryngol Pol. 2015; **69**(4): 34-9.
47. **Damen GW, Beynon AJ, Krabbe PF, Mulder JJ, Mylanus EA.** Cochlear implantation and quality of life in postlingually deaf adults: long-term follow-up. Otolaryngol Head Neck Surg. 2007; **136**(4): 597-604.
48. **Francis HW, Chee N, Yeagle J, Cheng A, Niparko JK.** Impact of cochlear implants on the functional health status of older adults. Laryngoscope. 2002; **112**(8 Pt 1): 1482-8.

49. **Lenarz T, Muller L, Czerniejewska-Wolska H, et al.** Patient-related benefits for adults with cochlear implantation: a multicultural longitudinal observational study. Audiol Neurootol. 2017; **22**(2): 61-73.
50. **Müller L, Graham P, Kaur J, Wyss J, Greenham P, James CJ.** Factors contributing to clinically important health utility gains in cochlear implant recipients. Eur Arch Otorhinolaryngol. 2021; **278**: 4723-31. https://doi.org/10.1007/s00405-020-06589-1.
51. **Palmer CS, Niparko JK, Wyatt JR, Rothman M, e Lissovoy G.** A prospective study of the cost-utility of the multichannel cochlear implant. Arch Otolaryngol Head Neck Surg. 1999; **125**(11): 1221-8.
52. **Ramakers GG, Smulders YE, van Zon A, et al.** Agreement between health utility instruments in cochlear implantation. Clin Otolaryngol. 2016; **41**(6): 737-43.
53. **Runge CL, Henion K, Tarima S, Beiter A, Zwolan TA.** Clinical Outcomes of the Cochlear™ Nucleus(®) 5 Cochlear Implant System and SmartSound™ 2 Signal Processing. J Am Acad Audiol. 2016; **27**(6): 425-40.
54. **Sladen DP, Gifford RH, Haynes D, et al.** Evaluation of a revised indication for determining adult cochlear implant candidacy. Laryngoscope. 2017; **127**(10): 2368-74.
55. **Smulders YE, van Zon A, Stegeman I, et al.** Cost-utility of bilateral versus unilateral cochlear implantation in adults: a randomized controlled trial. Otol Neurotol. 2016; **37**(1): 38-45.
56. **Zwolan TA, Henion K, Segel P, Runge C.** The role of age on cochlear implant performance, use, and health utility: a multicenter clinical trial. Otol Neurotol. 2014; **35**(9): 1560-8.
57. **Sarant J, Harris D, Busby P, et al.** The Effect of Cochlear Implants on Cognitive Function in Older Adults: Initial Baseline and 18-Month Follow Up Results for a Prospective International Longitudinal Study. Front Neurosci. 2019; **13**: 789.
58. **Klop WM, Boermans PP, Ferrier MB, van den Hout WB, Stiggelbout AM, Frijns JH.** Clinical relevance of quality of life outcome in cochlear implantation in postlingually deafened adults. Otol Neurotol. 2008; **29**(5): 615-21.
59. **Hawthorne G, Hogan A, Giles E, et al.** Evaluating the health-related quality of life effects of cochlear implants: a prospective study of an adult cochlear implant program. Int J Audiol. 2004; **43**(4): 183-92.
60. **Muigg F, Bliem HR, Kühn H, Seebacher J, Holzner B, Weichbold VW.** Cochlear implantation in adults with single-sided deafness: generic and disease-specific long-term quality of life. Eur Arch Otorhinolaryngol. 2020; **277**(3): 695-704.
61. **Bichey BG, Miyamoto RT.** Outcomes in bilateral cochlear implantation. Otolaryngol Head Neck Surg. 2008; **138**(5): 655-61.
62. **Chen JM, Amoodi H, Mittmann N.** Cost-utility analysis of bilateral cochlear implantation in adults: a health economic assessment from the perspective of a publicly funded program. Laryngoscope. 2014; **124**(6): 1452-8.
63. **Kuthubutheen J, Mittmann N, Amoodi H, Qian W, Chen JM.** The effect of different utility measures on the cost-effectiveness of bilateral cochlear implantation. Laryngoscope. 2015; **125**(2): 442-7. https://doi.org/10.1002/lary.24902.
64. **Sanhueza I, Manrique-Huarte R, Calavia D, Huarte A, Manrique M.** Hearing impairment and quality of life in adults with asymmetric hearing loss: benefits of bimodal stimulation. J Int Adv Otol. 2019; **15**(1): 62-9.
65. **Theriou C, Fielden CA, Kitterick PT.** The cost-effectiveness of bimodal stimulation compared to unilateral and bilateral cochlear implant use in adults with bilateral severe to profound deafness. Ear Hear. 2019; **40**(6): 1425-36.
66. **Wyatt JR, Niparko JK, Rothman M, eLissovoy G.** Cost utility of the multichannel cochlear implants in 258 profoundly deaf individuals. Laryngoscope. 1996; **106**(7): 816-21.
67. **Krabbe PF, Hinderink JB, van den Broek P.** The effect of cochlear implant use in postlingually deaf adults. Int J Technol Assess Health Care. 2000; **16**(3): 864-73.
68. **Kasemsiri P, Thanawirattananit P, Yimtae K, et al.** The outcomes of cochlear implantation in Thailand: audiologic performance and quality of life. J Med Assoc Thail. 2018; **101**(5): S203-S10.
69. **Barton GR, Stacey PC, Fortnum HM, Summerfield AQ.** Hearing-impaired children in the United Kingdom, IV: cost-effectiveness of pediatric cochlear implantation. Ear Hear. 2006; **27**(5): 575-88.
70. **Cheng AK, Rubin HR, Powe NR, Mellon NK, Francis HW, Niparko JK.** Cost-utility analysis of the cochlear implant in children. JAMA. 2000; **284**(7): 850-6.
71. **Clark JH, Wang NY, Riley AW, et al.** Timing of cochlear implantation and parents' global ratings of children's health and development. Otol Neurotol. 2012; **33**(4): 545-52.
72. **Jianxin Q, Chongxian Y, Ariyaratne TV, et al.** Cost-effectiveness of pediatric cochlear implantation in rural China. Otol Neurotol. 2017; **38**(6): e75-e84.
73. **Liu H, Liu HX, Kang HY, Gu Z, Hong SL.** Evaluation on health-related quality of life in deaf children with cochlear implant in China. Int J Pediatr Otorhinolaryngol. 2016; **88**: 136-41.
74. **Lovett RE, Kitterick PT, Hewitt CE, Summerfield AQ.** Bilateral or unilateral cochlear implantation for deaf children: an observational study. Arch Dis Child. 2010; **95**(2): 107-12.
75. **Sach TH, Barton GR.** Interpreting parental proxy reports of (health-related) quality of life for children with unilateral cochlear implants. Int J Pediatr Otorhinolaryngol. 2007; **71**(3): 435-45.
76. **Sparreboom M, Snik AF, Mylanus EA.** Sequential bilateral cochlear implantation in children: quality of life. Arch Otolaryngol Head Neck Surg. 2012; **138**(2): 134-41.
77. **Semenov YR, Yeh ST, Seshamani M, et al.** Age-dependent cost-utility of pediatric cochlear implantation. Ear Hear. 2013; **34**(4): 402.
78. **Buchman CA, Herzog JA, McJunkin JL, et al.** Assessment of speech understanding after cochlear implantation in adult hearing aid users: a nonrandomized controlled trial. JAMA Otolaryngol Head Neck Surg. 2020; **146**(10): 1-9.
79. **Wick CC, Kallogjeri D, McJunkin JL, et al.** Hearing and quality-of-life outcomes after cochlear implantation in adult hearing aid users 65 years or older: a secondary analysis of a nonrandomized clinical trial. JAMA Otolaryngol Head Neck Surg. 2020; **146**(10): 1-8.
80. **Quentin Summerfield A, Barton GR, Toner J, et al.** Self-reported benefits from successive bilateral cochlear implantation in post-lingually deafened adults: randomised controlled trial. Int J Audiol. 2006; **45 Suppl 1**: S99-107.
81. **van Zon A, Smulders YE, Stegeman I, et al.** Stable benefits of bilateral over unilateral cochlear implantation after two years: A randomized controlled trial. Laryngoscope. 2017; **127**(5): 1161-8.
82. **Lin FR, Niparko JK.** Measuring health-related quality of life after pediatric cochlear implantation: a systematic review. Int J Pediatr Otorhinolaryngol. 2006; **70**(10): 1695-706.
83. **Crowson MG, Semenov YR, Tucci DL, Niparko JK.** Quality of life and cost-effectiveness of cochlear implants: a narrative review. Audiol Neurootol. 2017; **22**(4-5): 236-58.
84. **Mulrow CD, Aguilar C, Endicott JE, et al.** Quality-of-life changes and hearing impairment: a randomized trial. Ann Intern Med. 1990; **113**(3): 188-94.
85. **Borre ED, Diab MM, Ayer A, et al.** Evidence gaps in economic analyses of hearing healthcare: a systematic review. EClinicalMedicine. 2021; **35**: 100872.
86. **Drummond M.** Introducing economic and quality of life measurements into clinical studies. Ann Med. 2001; **33**(5): 344-9.
87. **Chien W, Lin FR.** Prevalence of hearing aid use among older adults in the United States. Arch Intern Med. 2012; **172**(3): 292-3.
88. **Fuentes-López E, Fuente A, Cardemil F, Valdivia G, Albala C.** Prevalence and associated factors of hearing aid use among older adults in Chile. Int J Audiol. 2017; **56**(11): 810-8.
89. **Bodington E, Saeed SR, Smith MC, Stocks NG, Morse RP.** A narrative review of the logistic and economic feasibility of cochlear implants in lower-income countries. Cochlear Implants Int. 2021; **22**(1): 7-16.
90. **Francis HW, Yeagle JA, Thompson CB.** Clinical and psychosocial risk factors of hearing outcome in older adults with cochlear implants. Laryngoscope. 2015; **125**(3): 695-702.
91. **Dunn CC, Noble W, Tyler RS, Kordus M, Gantz BJ, Ji H.** Bilateral and unilateral cochlear implant users compared on speech perception in noise. Ear Hear. 2010; **31**(2): 296-8.
92. **Dunn CC, Tyler RS, Oakley S, Gantz BJ, Noble W.** Comparison of speech recognition and localization performance in bilateral and unilateral cochlear implant users matched on duration of deafness and age at implantation. Ear Hear. 2008; **29**(3): 352-9.
93. **Arnoldner C, Lin VY, Honeder C, Shipp D, Nedzelski J, Chen J.** Ten-year health-related quality of life in cochlear implant recipients: prospective SF-36 data with SF-6D conversion. Laryngoscope. 2014; **124**(1): 278-82.
94. **Briggs R, Tykocinski M, Saunders E, et al.** Health-related quality-of-life outcomes from adult cochlear implantation: A cross-sectional survey. Cochlear Implants Int. 2001; **2**(2): 115-28.