Holistic assessment of cochlear implant outcomes using the international classification of functioning disability and health model : data analysis of a longitudinal prospective multicenter study

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Holistic Assessment of Cochlear Implant Outcomes using the International Classification of Functioning Disability and Health model: data analysis of a longitudinal prospective multicenter study

Abstract

Purpose: To study outcome after cochlear implantation using the Cochlear Implant (CI) outcome assessment protocol based on the International Classification of Functioning, Disability and Health (ICF) model (CI-ICF).

Methods: Raw data of a prospective, longitudinal, multicenter study was analyzed. Seventy-two CI candidates were assessed preoperatively and six months postoperatively using the CI-ICF protocol. Following tools were used: (1) Work Rehabilitation Questionnaire (WORQ), (2) Abbreviated Profile of Hearing Aid Benefit (APHAB), (3) Audio Processor Satisfaction Questionnaire (APSQ), (4) Speech, Spatial, and Qualities of Hearing Scale (SSQ12), (5) Hearing Implant Sound Quality Index (HISQUI19), (6) Nijmegen CI Questionnaire (NCIQ) (7) pure tone audiometry, (8) speech audiometry, (9) sound localization.

Results: There was a significant improvement of speech discrimination in quiet ($p = 0.015$; $p < 0.001$) and in noise ($p = 0.041$; $p < 0.001$), sound detection ($p < 0.001$), tinnitus ($p = 0.026$), listening ($p < 0.001$), communicating with – receiving – spoken messages ($p < 0.001$), conversation ($p < 0.001$), family relationships ($p < 0.001$), community life ($p = 0.019$), NCIQ total score and all subdomain scores ($p < 0.001$). Subjective sound localization significantly improved ($p < 0.001$), while psychometric sound localization did not. There was no significant subjective deterioration of vestibular functioning and no substantial change in sound aversiveness. CI users reported a high level of implant satisfaction postoperatively.

Conclusion: This study highlights the positive impact of cochlear implantation on auditory performance, communication, and subjective well-being. The CI-ICF protocol provides a holistic and comprehensive view of the evolution of CI outcomes.

Keywords: ICF, Cochlear Implant, CI outcomes, CI outcome evaluation

1. Introduction

Cochlear implantation is the most used intervention for severe-to-profound hearing loss. As of December 2019, roughly 739,000 registered cochlear implants (CI's) were implanted worldwide [1]. In the United States alone the number of individuals aged 12 years and older with bilateral profound hearing loss (> 80 dB hearing threshold in the best ear) is estimated at 350,000 Americans [2]. Sorkin and Buchman (2016) indicate that the pediatric CI adoption rate in high-income countries is generally high, but adult CI utilization is less than 10 percent worldwide. The low CI adoption rate in adults is largely caused by lack of patient referrals by primary care physicians and audiologists due to unfamiliarity with CI candidacy criteria and outcomes and the lack of CI awareness [3, 4]. Nevertheless, an increasing number of studies have demonstrated the positive effects of cochlear implantation on hearing abilities, quality of life (QoL) and cognitive functioning in (older) adults with severe-to-profound hearing loss [5-9].

Overall, speech recognition in quiet and in noise significantly improve after cochlear implantation with large individual variation in scores [10]. The improvement in speech recognition scores is related to the postoperative QoL of CI users but can only predict a small fraction of the variability in QoL outcomes in this population [11]. CI users' QoL is most commonly measured by generic or disease-specific questionnaires in literature. Multiple studies have shown that disease-specific questionnaires such as the Nijmegen Cochlear implant Questionnaire (NCIQ) are better able to demonstrate long-term and short-term QoL changes after cochlear implantation than generic questionnaires such as the Health utilities Index (HUI) [7, 12]. However, most disease-specific QoL questionnaires for adults with hearing loss focus on hearing performance and do not provide a holistic view of the impact of hearing loss on an individual's life [13]. In addition, several recent literature reviews on adults' CI outcomes denounce the wide variety of instruments and methods used and recommend minimum reporting standards and standardization of test material and conditions [8, 14]. Therefore, Andries et al. (2023) defined a standardized multidimensional CI outcome assessment protocol based on the International Classification of Functioning, Disability, and Health (ICF) model and its core set for hearing loss developed by Danermark et al. [15, 16].

The multifaceted nature of cochlear implantation and the complex interplay between biological, psychological, and social factors highlight the need for a multidisciplinary approach when evaluating its impact on individuals' lives [17]. It is crucial to not only measure the audiological aspects of hearing restoration but also to comprehend how this intervention translates into broader domains of daily living. This encompasses its influence on communication, social functioning, emotional well-being, and overall QoL. The ICF model, developed by the World Health Organization (WHO) in 2001, offers a framework for addressing this multidimensionality by providing a standardized description of individuals' health status, functioning and disability [16]. The model consists of four components: body functions and structures, activities and participation, environmental factors and personal factors, including various ICF codes and categories. Andries et al. (2023) implemented the ICF model in CI users to provide a comprehensive description, categorization and measurement of CI outcomes worldwide [18]. Four recent publications also applied the ICF model in the field of cochlear implantation; (1) Mertens et al. (2022) defined the HEARRING_LOC_ICF scale to categorize CI users according to their sound localization performance, (2) Andries et al. (2022) revised the ICF-based Work Rehabilitation Questionnaire (WORQ) to include only items relevant to CI users, (3) Lorens et al. (2023) described the ICF core sets for hearing loss that can be used to plan and evaluate the holistic (re)habilitation of CI recipients and (4) Illg et al. (2023) developed the Quality of Life in People with Hearing Loss Questionnaire (HL-QoL) based on the ICF to provide a holistic perspective on how HL can impact an individual's QoL [13, 19-21]. The study of Andries et al. (2023) focused on implementing the ICF model and its descriptive classification system in CI users and did not perform statistical test comparisons on the raw data collected using the ICF-based CI outcome assessment protocol. The aim of this study was to investigate the evolution of CI outcomes after cochlear implantation using the raw data collected in the prospective, longitudinal, multicenter study of Andries et al. 2023.

2. Methods

2.1 Ethics

All participants gave their written informed consent in accordance with the Declaration of Helsinki prior to participation. The study was carried out in conformity with the recommendations of the local ethics committees and competing authorities (Antwerp 20/27/357; Madrid PI-4359; Perth RGS0000004350; Warsaw KB/3/2021; Würzburg 199/20). All patient data was anonymized prior to the respective analyses.

2.2 Design

This prospective observational longitudinal multicenter study was conducted in five participating centers: La Paz University Hospital (Madrid, Spain), the Antwerp University Hospital (Antwerp, Belgium), the Fiona Stanley Fremantle Hospital Group (Perth, Australia), the University of Würzburg (Würzburg, Germany), and the World Hearing Center (Warsaw, Poland) over a 2-year period (August 2020 – August 2022). The study protocol was retrospectively registered at Clinical Trials (Clinicaltrials.gov) on November 2, 2020 (identifier: NCT04611555).

2.3 Participants

This study included a consecutive sample of CI candidates (1) with unilateral or bilateral postlingual severe-to-profound hearing loss, (2) aged 18 years or older, (3) qualified and scheduled for cochlear implantation based on the candidate selection criteria established by their respective local implantation centers. Participants were assessed one month prior to the implantation procedure and again six months following activation of the audio processor. To participate, candidates needed to demonstrate fluency in the language used at the implanting center and receive their first CI. The activation of the audio processor occurred approximately four weeks after the surgical procedure, with subsequent optimization of its settings taking place during regular clinical programming sessions. Exclusion criteria encompassed cases involving CI reimplantation, the presence of contraindications for surgery in general, and contraindications specific to cochlear implantation.

2.4 CI outcome assessment

2.4.1 Questionnaires:

All of the following questionnaires are available in Flemish, English, German, Polish, and Spanish and were completed by each participant during a routine clinic visit, via e-mail or by mail preoperatively and 6 months post CI activation. The total score, subdomain scores or specific questions of each questionnaire, except for the NCIQ, correspond to an ICF component, ICF code and ICF category in the ICF-based outcome assessment protocol. More details on this protocol and its development can be found in Andries et al. (2023).

2.4.1.1 The Work Rehabilitation Questionnaire (WORQ)

The original 59-item ICF-based WORQ was developed to holistically assess functioning in vocational rehabilitation [22]. It was revised and shortened to include 17 items relevant to CI users, divided into two parts [19]. Part 1 consists of 3 items on work status and education level and part 2 features 14 items on functioning. In part 2, participants have to rate to what extent they had problems with a certain activity or task in the last week using a numerical scale ranging from 0 (no problem) to 10 (complete problem). The evolution of the questions included in part 1 of the WORQ was not analyzed in this study due to the questions' demographic nature and the short follow-up period.

2.4.1.2 The Abbreviated Profile of Hearing Aid Benefit (APHAB)

The APHAB [23] is a 24-item questionnaire derived from the original 66-item Profile of Hearing Aid Benefit. The self-assessment instrument evaluates consequences of hearing impairment for functioning in real-life situations with and without hearing aids. Participants must rate how often a given statement is true in their daily life, based on the following seven response alternatives: always (99%), almost always (87%), generally (75%), half-the-time (50%), occasionally (25%), seldom (12%) and never (1%). Ease of communication, reverberation, background noise and aversiveness of sounds make up the four subscales of APHAB. Higher scores suggest more hearing disability, while lower scores indicate less hearing disability. The APHAB total score is the mean of the scores for all the items in the ease of communication, reverberation, and background noise subscales (not including the aversiveness subscale). The APHAB total score and the APHAB aversiveness score were used to measure the following ICF categories: codes and components: "d310 Communicating with – receiving – spoken messages", categorized under activities and participation, and "e250 Sound", categorized under environmental factors, respectively.

2.4.1.3 The Audio Processor Satisfaction Questionnaire (APSQ)

The APSQ [24] measures user's satisfaction with their audio processor(s) for the following three domains: usability, wearing comfort, and social life, using 15 items on a VAS scale from 0 (does not agree at all) to 10 (fully agrees). Participants completed the APSQ 6 months post activation of the audio processor. The APSQ total score measures "e125 Products and technology for communication" under the environmental factors component in the ICF-based outcome assessment protocol.

2.4.1.4 The Speech, Spatial, and Qualities of Hearing Questionnaire with 12 items (SSQ12)

The SSQ12 [25] is designed to measure self-reported auditory disability across a wide variety of domains, reflecting the reality of hearing in the everyday world. It covers hearing speech in a variety of competing contexts; the directional, distance, and movement components of spatial hearing; segregation of sounds and attending to simultaneous speech streams; ease of listening; the naturalness, clarity, and identifiability of different speakers; different musical pieces and instruments; and different everyday sounds. The SSQ12 consists of 12 questions divided across three subscales (Speech, Spatial and Qualities of Hearing) that subjects score on a scale from 0 (not at all) to 10 (perfectly). The total score is the mean of all items, subscale scores are the mean of all items in that subscale. The SSQ12 Spatial subscale score was used to measure 'b2302 Localization of sound source", categorized under the ICF component body functions and structures.

2.4.1.5 The Hearing Implant Sound Quality Index 19 (HISQUI19)

The HISQUI19 [26] is a self-administered questionnaire to quantify the individual perceived sound quality of hearing implanted patients in daily life. The questionnaire consists of 19 seven-level Likert items ranging from "always (99%)" to "never (1%)". Added percentage values support the answering. The total score is the sum of all items and ranges from 19 to 133 points. It measures "d115 Listening" under the activities and participation component in the ICF-based outcome assessment protocol.

2.4.1.6 The Nijmegen Cochlear Implant Questionnaire (NCIQ)

The NCIQ [27] is a 60-item self-assessment instrument assessing quality of life on psychological, physical, and social domain in CI users. NCIQ consists of the following six subdomains: basic sound perception, advanced sound perception, speech production, self-esteem, activity, and social interaction. Items are formulated as statements with the following 5 response alternatives indicating the degree to which the statement is true: never (1), sometimes (2), often (3), mostly (4) and always (5). Response alternatives of five of the 60 items represent the CI user's ability to perform the stated task and are as follows: no (1), poorly (2), moderate (3), adequate (4) and good (5). Not applicable can also be answered throughout the questionnaire.

2.4.2 Audiological examinations:

2.4.2.1 Pure tone audiometry

Pure tone audiometry was performed according to current clinical standards (ISO 8253-1, 2010). Pre- and postoperatively, best-aided pure tone audiometry was measured at 500, 1000, 2000, 4000 and 8000 Hz in sound field using warble tones in a sound treated booth. The loudspeaker was placed in front of the participant at ear level at 1-meter distance. The best-aided pure tone average (PTA4) was calculated by averaging the hearing thresholds of the participants at 500, 1000, 2000 and 4000 Hz in best-aided condition. The PTA4 was used to measure "b2300 Sound detection" under the body functions and structures component in the ICF-based outcome assessment protocol.

2.4.2.2 Speech intelligibility

Speech intelligibility was evaluated in noise, using sentences, and in quiet, using disyllables in Spanish and monosyllables in the other languages. These tests were performed in best-aided situation pre- and postoperatively according to current clinical standards (ISO 8253-1, 2010). Participants sat at a one-meter distance in front of the loudspeaker, which was positioned at ear level. They were instructed to repeat the speech stimuli they heard. Detailed information about the used speech tests per center can be found in Appendix 1. Speech audiometry in quiet and in noise measure the following ICF code, category and component: "b2304 Speech discrimination" under body functions and structures.

2.4.2.3 Sound localization testing

Each center used its own localization set-up, all meeting the localization testing standards published by Van de Heyning et al. 2017 [28]. Norm values were based on the current set-up in each participating center. More detailed information on the localization set-up and norm values is described in Mertens at al. [20]. Centers not having an appropriate set-up at their disposal only used the SSQ12 spatial subscale. Localization test scores were used to measure: "b2302 Localization of sound source", categorized under the body functions and structures ICF component.

2.4.3 Subject demographics

Subject demographics were retrieved from the participants' medical records or by asking them if the information was not available. The following information was collected: age, gender, ear to be implanted, aetiology, type and onset of hearing loss, preoperative hearing aid use, previous ear surgery and otological condition. The participants' hearing loss aetiology was coded according to the 11th revision of the International Statistical Classification of Diseases and Related Health Problems (ICD-11).

2.5 Statistics

IBM SPSS Statistics v24 (IBM, Armonik, New York) was used to perform the statistical analysis. To compare APHAB, WORQ, NCIQ, SSQ12, HISQUI19, and pure tone audiometry data over time, a paired t-test was used. Speech audiometry in quiet and in noise data was divided by language (English, Flemish, German, Polish, and Spanish) due to the difference in test materials and scores for each language. Localization testing data was divided per center (Poland, Belgium) due to the different localization setups used. In addition, SSQ12 Spatial and localization testing data were divided by fitting type [unilateral CI, bilateral CI, Single Sided Deafness (SSD), Electric Acoustic Stimulation (EAS), and bimodal (CI ipsilateral and hearing aid contralateral)] due to the expected influence of this factor on the results for this category. Due to the small sample sizes of these subgroups, the non-parametric Wilcoxon Signed Ranks test was used to compare the data over time.

3. Results

The results section is divided into four subsections. The first three subsections correspond to three components of the ICF model: body functions and structures, activities and participation and environmental factors, and report the raw data analysis results of the ICF-based CI outcome assessment protocol. The last section includes overall CI-specific QoL outcomes measured with the NCIQ. Detailed information on the participants' characteristics can be found in Table 1.

3.1 Body functions and structures

There was a significant improvement of speech discrimination in quiet (SPIQ) after cochlear implantation in the following languages: Flemish (mean difference 18.44; $Z = 2.43$; $p = 0.015$), English (mean difference 58; $Z = -2.52$; $p = 0.012$), Polish (mean difference 26.8; $Z = -3.93$; $p < 0.001$) and Spanish (mean difference 26.8; $Z = -3.93$; $p < 0.001$). Speech discrimination in noise (SPIN) also improved significantly in these languages: Flemish (mean difference -7.86; $Z = -3.65$; $p < 0.001$), English (mean difference 4.07; $Z = -2.05$; $p = 0.041$), Polish (mean difference 1.75; $Z = -2.08$; $p = 0.037$) and Spanish (mean difference 39.92; $Z = -2.7$; $p = 0.007$). No statistical analysis was performed for SPIQ and SPIN in German because the sample size was too small ($n = 2$) to obtain reliable results. Additionally, sound detection (PTA4) (mean difference 23.06; $t = 8.29$; $p < 0.001$) and tinnitus (WORQ question 7) (mean difference 1.06; $t = 2.28$; $p = 0.026$) significantly improved after implantation. More details are presented in Figure 1.

There was a significant improvement of sound localization measured with the SSQ12 Spatial subdomain score (mean difference -1.56; $t = -4.67$; $p < 0.001$), while sound localization measured with localization testing did not improve significantly (Poland: mean difference 6.44; $Z = -1.63$; $p = 0.104$; Belgium: mean difference -20.6; $Z = -1.15$; $p = 0.249$). Looking into the different fitting types, the SSQ12 Spatial data improved significantly for bimodal (CI ipsilateral, hearing aid contralateral) (mean difference -1.89; $Z = -3.65$; $p < 0.001$), but no significant improvement was demonstrated for the other fitting types: EAS (mean difference -1.39; $Z = -1.89$; $p = 0.058$), unilateral CI (mean difference -0.97; $Z = -1.59$; $p = 0.112$). Localization testing results did not improve for any fitting type: EAS (mean difference 10.13; $Z = -1.99$; $p = 0.05$), unilateral CI (mean difference -3.6; $Z = -0.41$; $p = 0.69$), or bimodal (mean difference 4.18; $Z = -0.86$; $p = 0.39$). Only the Polish localization testing data was analyzed per fitting type due to the small sample size of the Belgian data. No statistical analysis was performed for localization testing and SSQ12 Spatial in bilateral CI users or SSD because the sample size was too small to obtain reliable results. More details are presented in Figure 1 and 2.

No significant improvement was observed for the WORQ questions concerning energy and drive functions (mean difference -1.41; $t = -0.45$; $p = 0.65$), emotional functions: sad or depressed (mean difference 0; $t = 0$; $p = 1$) and worried or anxious (mean difference 0.02; $t = 0.05$; $p = 0.962$), dizziness (mean difference 0.08; t = 0.21; p = 0.83), vestibular functions (mean difference -0.56; t = -1.46; p = 0.15), vertigo (mean difference -0.18; t = -0.49; p = 0.62), and sensation of falling (mean difference -0.42; t = -1.81; p = 0.08). More details are presented in Figure 1.

3.2 Activities and participation

A significant improvement was observed for listening (HISQUI19 total score) (mean difference 18.3; t = -7.25; p < 0.001;), communicating with – receiving – spoken messages (APHAB total score) (mean difference 20; t = 8.08; p < 0.001), conversation (WORQ question 11) (mean difference 1.64; t = 4.19; p < 0.001), family relationships (WORQ question 14) (mean difference 1.21; t = 3.51; p < 0.001) and community life (mean difference: 1.05; t = 2.40; p = 0.019). Carrying out daily routine (mean difference: 0.06; t = -0.16; p = 0.87), stress (mean difference 0.53; t = 1.47; p = 0.15), communication devices and techniques (mean difference 0.71; t = 1.47; p = 0.15), measured with the revised WORQ for CI users, did not improve significantly. More details are presented in Figure 3.

3.3 Environmental factors

No significant change was observed for sound (APHAB aversiveness) (mean difference -3.96; t = 1.20; p = 0.23) and CI users reported a mean score of 8.11 out of 10 for products and technology for communication (APSQ total score) after implantation. More details are presented in Figure 4.

3.4 Overall Cochlear Implant-specific quality of life

A significant improvement of overall CI-specific QoL (NCIQ total score) (mean difference -13.32; t = -8.15; p < 0.001) and all NCIQ subdomain scores; basic sound perception (mean difference -17.33; t = -6.93; p < 0.001), speech production (mean difference -6.89; t = -3.78; p < 0.001), advanced sound perception (mean difference -13.67; t = -6.58; p < 0.001), self-esteem (mean difference -11.01; t = -5.72; p < 0.001), activity limitations (mean difference -14.17; t = -6.93; p < 0.001) and social interactions (mean difference -17.08; t = -7.47; p < 0.001), was demonstrated after implantation. More details are presented in Figure 5.

4. Discussion

This study aimed to investigate the evolution of CI outcomes after cochlear implantation using the raw data collected in the prospective, longitudinal, multicenter study of Andries et al. 2023 using the ICF-based CI outcome assessment protocol. Our analysis demonstrated that cochlear implantation leads to substantial improvements in hearing abilities, facilitating improved speech understanding in both quiet and noisy environments and enhancing communication, which concurs with previous research [8, 10]. Not only psychoacoustic measures, such as speech audiometry, demonstrated significant improvements, CI users also reported a substantial subjective benefit derived from cochlear implantation, measured with various patient-reported outcome measures (PROMs). The combination of these PROMs and psychoacoustic measures in CI outcome evaluation provides a holistic view of the evolution of CI outcomes by covering not only body functions and structures impairments (e.g., hearing loss), but also activity limitations and participation restrictions as well as environmental barriers. The ICF-based CI outcome assessment protocol used in this study, therefore, holds the potential to address the identified need from prior research for a more comprehensive methodology in assessing CI outcomes, while also assuring methodological uniformity in the evaluation of these outcomes

In this study, CI users experienced significantly fewer problems related to tinnitus after implantation, confirming recent research showing that between 50% and 68% of CI candidates benefit from complete or partial tinnitus suppression after implantation [29-31]. To maximize the benefit of cochlear implantation concerning tinnitus, CI users still experiencing tinnitus burden after implantation should be identified and followed-up and their needs should be addressed to the extent possible. The CI users in our study also reported significantly fewer problems with family relationships and community life after implantation, possibly because of the substantial improvement in communication provided by a CI that could lead to less social inhibition and more social engagement [32, 33]. Furthermore, the high level of implant satisfaction and the lack of substantial change in sound aversiveness highlight the successful adaptation of CI users to their implants. These findings underscore the importance of comprehensive patient counseling and support in maximizing the benefits of a CI. Cochlear implantation did not induce significant changes in vestibular symptoms, as expected [34]. The absence of significantly increased balance problems post-implantation is reassuring and provides valuable information regarding the safety of CI surgery in adults.

A notable discrepancy emerged in the assessment of sound localization. While the SSQ12 Spatial results suggest significant improvements, localization testing failed to consistently validate these findings. This could partly be explained by the fact that clinical localization testing may not be fully representative of localization abilities in real-life situations, which the SSQ12 Spatial is more focused on. The reliability of localization testing might also have been affected by the test time of the localization test and by the fact that patients often had multiple tests within the same follow-up appointment which could impact their attention level during testing. It is also important to note that the smaller sample size (n = 20 Poland and n = 7 Belgium) in the localization testing group might have limited statistical power. Future studies should aim to elucidate the factors contributing to the potential divergence between subjective localization benefit and psychoacoustic outcomes and the clinical implications thereof. The localization data was divided into subgroups according to fitting type [unilateral CI, bilateral CI, SSD, EAS, and bimodal (CI ipsilateral and hearing aid contralateral)] because of the possible effect of CI fitting type on psychoacoustic and subjective localization scores [35]. For example, the localization benefit of CI users with unilateral CI is expected to be less than that of bimodal, SSD or bilateral CI users as the latter have binaural hearing and can take advantage of the head shadow effect, interaural time difference and interaural level difference cues. In our study, bimodal CI users' subjective localization significantly improved, while no significant improvement was found for the other fitting types. Recent studies with larger sample sizes, however, did show a significant improvement of subjective and psychoacoustic localization testing after cochlear implantation for SSD [36], bilateral CI [37], EAS [38], and bimodal hearing [39].

Energy and drive functions, emotional functions, carrying out daily routine, stress and using communication devices and techniques did not change significantly after implantation. This could be due to the fact that most CI candidates already reported few problems before implantation (mean score between 2 and 3.1 preoperatively) for these ICF categories and their corresponding WORQ question(s). Using communication devices and techniques, such as smartphones or computers, proved harder for most participants (mean score of 4.3 preoperatively). This may be related to telephone communication issues associated with hearing loss, for example, resulting from the reduced transmission bandwidth of a telephone signal [40]. In addition, older adults generally experience some degree of difficulty handling technology due to poor readability, compressed keys, etc. which could also partially explain this result [41].

The results of the NCIQ, measuring CI-specific QoL, confirm the findings of the assessment tools included in the ICF-based CI outcome protocol. The NCIQ was not included in this protocol due to its length (60 questions) and because other instruments were more suitable to assign to the ICF categories that were incorporated in the protocol. The NCIQ, for example, does not include items regarding environmental factors (e.g., sound aversiveness or implant satisfaction) and mainly focuses on activity limitations and participation restrictions linked to emotional wellbeing [42]. The mean score of our participants pre- and 6 months postoperatively concurs with those found in previous studies, suggesting our study sample to be representative [43, 44]. The Cochlear Implant Quality of Life questionnaire, developed by McRackan et al. (2019), was not included in this study or in the ICF-based CI outcome assessment protocol because the questionnaire is currently not available in the languages of all participating centers [42]. Furthermore, this study exclusively focused on individuals with MED-EL straight-electrode arrays to exclude potential confounding factors regarding different electrode designs.

A limitation of this study is the small sample size of the subgroups for speech audiometry divided by language (Flemish, Polish, German, English, Spanish) and localization testing divided by fitting type (EAS, SSD, unilateral CI, bimodal, bilateral CI). Future studies should recruit more participants to further explore the effect of language and fitting type on these variables. A consecutive sample of CI candidates, including adults with unilateral and bilateral postlingual hearing loss, was recruited for this study to obtain a representative sample of the current CI population in our participating centers. Potential differences between CI indication groups were only evaluated for localization data in this paper, but will be described in detail in a future article on the influence of CI indications on CI outcomes. Additionally, the SSQ12 and APHAB questionnaires are not specifically developed or validated for CI users or individuals with severe-to-profound hearing loss [23, 25]. However, they are internationally available, commonly used and accepted in literature and clinical routine in the field of cochlear implantation and they are a suitable measurement tool for the selected ICF categories in the ICF-based CI outcome assessment protocol [14]. While cognitive functioning was not included in our analysis, it is noteworthy that this aspect may hold particular relevance for older adult populations [5, 6, 9]. Future studies should consider incorporating cognitive assessments adjusted for hearing loss, such as the RBANS-H [45], to gain insights into the potential cognitive benefits of cochlear implantation in specific age groups. During the six months follow-up time, the evolution of all outcomes might not be fully covered. Aspects of participation, for example, may continue to evolve favorably up to 12 months e.g., in older patients. Future studies should therefore consider a longer outcome follow-up time after cochlear implantation.

5. Conclusion

This study contributes insights into the multifaceted outcomes of cochlear implantation, highlighting its positive impact on auditory performance, communication, and subjective well-being. It provides a holistic and comprehensive view of the evolution of CI outcomes by not only covering body functions and structures outcomes, such as hearing abilities, but also including results concerning activities and participation as well as environmental factors.

6. References

1. National Institute on Deafness and Other Communication Disorders. *Cochlear Implants*. 2021 21/08/2023, .]; Available from: https://www.nidcd.nih.gov/health/cochlear-implants.
2. Goman, A.M. and F.R. Lin, *Prevalence of Hearing Loss by Severity in the United States.* Am J Public Health, 2016. **106**(10): p. 1820-2.
3. Sorkin, D.L. and C.A. Buchman, *Cochlear Implant Access in Six Developed Countries.* Otol Neurotol, 2016. **37**(2): p. e161-4.
4. D'haese, P.S.C., et al., *Awareness of Hearing Loss in Older Adults: Results of a Survey Conducted in 500 Subjects Across 5 European Countries as a Basis for an Online Awareness Campaign.* INQUIRY: The Journal of Health Care Organization, Provision, and Financing, 2018. **55**.
5. Mertens, G., et al., *Cognitive Improvement After Cochlear Implantation in Older Adults With Severe or Profound Hearing Impairment: A Prospective, Longitudinal, Controlled, Multicenter Study.* Ear Hear, 2020. **42**(3): p. 606-614.
6. Andries, E., et al., *Evaluation of Cognitive Functioning Before and After Cochlear Implantation in Adults Aged 55 Years and Older at Risk for Mild Cognitive Impairment.* JAMA Otolaryngol Head Neck Surg, 2023. **149**(4): p. 310-316.
7. Weichbold, V., et al., *5-Year Observation Period of Quality of Life After Cochlear Implantation.* Otol Neurotol, 2023. **44**(3): p. e155-e159.
8. Boisvert, I., et al., *Cochlear implantation outcomes in adults: A scoping review.* PLoS One, 2020. **15**(5): p. e0232421.
9. Kay-Rivest, E., J. Schlacter, and S.B. Waltzman, *Cochlear implantation outcomes in the older adult: a scoping review.* Cochlear Implants Int, 2022: p. 1-11.
10. Ma, C., et al., *Longitudinal Speech Recognition Changes After Cochlear Implant: Systematic Review and Meta-analysis.* Laryngoscope, 2023. **133**(5): p. 1014-1024.
11. Walia, A., et al., *Predictors of Short-Term Changes in Quality of Life after Cochlear Implantation.* Otol Neurotol, 2023. **44**(3): p. e146-e154.
12. Andries, E., et al., *The impact of cochlear implantation on health-related quality of life in older adults, measured with the Health Utilities Index Mark 2 and Mark 3.* Eur Arch Otorhinolaryngol, 2022. **279**(2): p. 739-750.
13. Illg, A., et al., *A holistic perspective on hearing loss: first quality-of-life questionnaire (HL-QOL) for people with hearing loss based on the international classification of functioning, disability, and health.* Frontiers in Audiology and Otology, 2023. **1**.
14. Andries, E., et al., *Systematic review of quality of life assessments after cochlear implantation in older adults.* Audiology & Neurotology, 2020: p. 1-15.
15. Danermark, B., et al., *The creation of a comprehensive and a brief core set for hearing loss using the international classification of functioning, disability and health.* Am J Audiol, 2013. **22**(2): p. 323-8.
16. World Health Organization, *International classification of functioning, disability and health.* 2001, World Health Organization: Geneva.
17. Meyer, C., et al., *What Is the International Classification of Functioning, Disability and Health and Why Is It Relevant to Audiology?* Semin Hear, 2016. **37**(3): p. 163-86.
18. Andries, E., et al., *Implementation of the International Classification of Functioning, Disability and Health model in cochlear implant recipients: a multi-center prospective follow-up cohort study.* Frontiers in Audiology and Otology, 2023. **1**.
19. Andries, E., et al., *Evaluating the Revised Work Rehabilitation Questionnaire in Cochlear Implant Users Cochlear Implant Outcome Assessment Based on the International Classification of Functioning, Disability, and Health (ICF).* Otol Neurotol, 2022. **43**(5): p. e571-e577.
20. Mertens, G., et al., *Towards a Consensus on an ICF-Based Classification System for Horizontal Sound-Source Localization.* Journal of Personalized Medicine, 2022. **12**(12): p. 1971.

21. Lorens, A., et al., *Holistic rehabilitation of cochlear implant users: using the International Classification of Functioning, Disability and Health.* Journal of Hearing Science, 2023. **13**(1): p. 19-25.
22. Finger, M., et al., *Work Rehabilitation Questionnaire (WORQ): Development and Preliminary Psychometric Evidence of an ICF-Based Questionnaire for Vocational Rehabilitation.* Journal of Occupational Rehabilitation, 2014. **24**(3): p. 498-510.
23. Cox, M.R. and C.G. Alexander, *The Abbreviated Profile of Hearing Aid Benefit.* Ear and Hearing, 1995. **16**(2): p. 176-186.
24. Billinger-Finke, M., et al., *Development and validation of the audio processor satisfaction questionnaire (APSQ) for hearing implant users.* Int J Audiol, 2020: p. 1-6.
25. Noble, W., et al., *A short form of the Speech, Spatial and Qualities of Hearing scale suitable for clinical use: the SSQ12.* Int J Audiol, 2013. **52**(6): p. 409-12.
26. Amann, E. and I. Anderson, *Development and validation of a questionnaire for hearing implant users to self-assess their auditory abilities in everyday communication situations: the Hearing Implant Sound Quality Index (HISQUI19).* Acta Otolaryngol, 2014. **134**(9): p. 915-23.
27. Hinderink, J.B., P.F. Krabbe, and P. Van Den Broek, *Development and application of a health-related quality-of-life instrument for adults with cochlear implants: the Nijmegen cochlear implant questionnaire.* Otolaryngol Head Neck Surg, 2000. **123**(6): p. 756-65.
28. Van de Heyning, P., et al., *Towards a Unified Testing Framework for Single-Sided Deafness Studies: A Consensus Paper.* Audiology and Neurotology, 2017. **21**(6): p. 391-398.
29. Rasmussen, K.D., et al., *Tinnitus suppression in a prospective cohort of 45 cochlear implant recipients: occurrence, degree and correlates.* Eur Arch Otorhinolaryngol, 2023. **280**(9): p. 4073-4082.
30. James, C.J., et al., *The Listening Network and Cochlear Implant Benefits in Hearing-Impaired Adults.* Front Aging Neurosci, 2021. **13**: p. 589296.
31. Mertens, G., M. De Bodt, and P. Van de Heyning, *Cochlear implantation as a long-term treatment for ipsilateral incapacitating tinnitus in subjects with unilateral hearing loss up to 10 years.* Hear Res, 2016. **331**: p. 1-6.
32. Andries, E., et al., *Evolution of Type D Personality Traits After Cochlear Implantation in Severely Hearing Impaired Adults 55 Years and Older: An Exploratory Prospective, Longitudinal, Controlled, Multicenter Study.* Otol Neurotol, 2022. **43**(8): p. e865-e871.
33. Bekele Okuba, T., et al., *Cochlear implantation impact on health service utilisation and social outcomes: a systematic review.* BMC Health Serv Res, 2023. **23**(1): p. 929.
34. Stuermer, K.J., et al., *Preservation of Vestibular Function and Residual Hearing After Round Window Cochlear Implantation.* Otol Neurotol, 2019. **40**(7): p. 878-882.
35. Pieper, S.H., et al., *Considerations for Fitting Cochlear Implants Bimodally and to the Single-Sided Deaf.* Trends Hear, 2022. **26**: p. 23312165221108259.
36. Morelli, L., et al., *Cochlear implantation in single-sided deafness: a single-center experience of 138 cases.* Eur Arch Otorhinolaryngol, 2023. **280**(10): p. 4427-4432.
37. Kraaijenga, V.J.C., et al., *No Difference in Behavioral and Self-Reported Outcomes for Simultaneous and Sequential Bilateral Cochlear Implantation: Evidence From a Multicenter Randomized Controlled Trial.* Front Neurosci, 2019. **13**: p. 54.
38. Plant, K. and L. Babic, *Utility of bilateral acoustic hearing in combination with electrical stimulation provided by the cochlear implant.* Int J Audiol, 2016. **55 Suppl 2**: p. S31-8.
39. van Loon, M.C., et al., *Cochlear Implantation in Adults With Asymmetric Hearing Loss: Benefits of Bimodal Stimulation.* Otol Neurotol, 2017. **38**(6): p. e100-e106.
40. Anderson, I., et al., *Telephone use: What benefit do cochlear implant users receive?* International journal of audiology, 2006. **45**(8): p. 446-453.
41. Zhou, J., P.-L.P. Rau, and G. Salvendy, *Age-related difference in the use of mobile phones.* Universal access in the information society, 2014. **13**(4): p. 4001-413.

42. McRackan, T.R., et al., *Cochlear Implant Quality of Life (CIQOL): Development of a Profile Instrument (CIQOL-35 Profile) and a Global Measure (CIQOL-10 Global).* Journal of Speech, Language and Hearing Research (Online), 2019. **62**(9): p. 3554-3563.
43. Ovari, A., et al., *Functional Outcomes and Quality of Life after Cochlear Implantation in Patients with Long-Term Deafness.* J Clin Med, 2022. **11**(17).
44. Häußler, S.M., et al., *Long-term Benefit of Unilateral Cochlear Implantation on Quality of Life and Speech Perception in Bilaterally Deafened Patients.* Otology & Neurotology, 2019. **40**(4): p. e430-e440.
45. Claes, A.J., et al., *The Repeatable Battery for the Assessment of Neuropsychological Status for Hearing Impaired Patients (RBANS-H) before and after Cochlear Implantation: A Protocol for a Prospective, Longitudinal Cohort Study.* Frontiers in Neuroscience, 2016. **10**.