Health-Related Quality of Life Following Hearing Aid Treatment

a large Cohort study

Wolff, Anne

Publication date:
2019

Document Version
Publisher's PDF, also known as Version of record

HEALTH-RELATED QUALITY OF LIFE FOLLOWING HEARING AID TREATMENT

A LARGE COHORT STUDY

BY
ANNE WOLFF

DISSERTATION SUBMITTED 2019

AALBORG UNIVERSITY
DENMARK

HEALTH-RELATED QUALITY OF LIFE FOLLOWING HEARING AID TREATMENT

A LARGE COHORT STUDY

by

Anne Wolff, MD

AALBORG UNIVERSITY
DENMARK

Dissertation submitted

Dissertation submitted:	December 1st, 2019
PhD supervisor:	Professor Michael Gaihede MD, PhD, Dept. of Otolaryngology, Head and Neck Surgery and Audiology, Aalborg University Hospital, Denmark
Assistant PhD supervisors:	Associate professor Jesper H. Schmidt MD, PhD, Odense University Hospital
	Professor Dorte Hammershøi, Engineer, PhD, Aalborg University
	Associate professor Dan D. Hougaard, MD, Aalborg University Hospital
	Associate professor Gérard Loquet, PhD, Aalborg University
PhD committee:	Clinical Professor Thomas Starch-Jensen (chairman) Aalborg University / Aalborg University Hospital
	Professor Torbjörn Ledin Linköping University Hospital
	Professor Norbert Dillier Zurich University Hospital
PhD Series:	Faculty of Medicine, Aalborg University
Department:	Department of Clinical Medicine

ISSN (online): 2246-1302
ISBN (online): 978-87-7210-553-6

Published by:
Aalborg University Press
Langagervej 2
DK – 9220 Aalborg Ø
Phone: +45 99407140
aauf@forlag.aau.dk
forlag.aau.dk

Printed in Denmark by Rosendahls, 2020

CURRICULUM VITAE

- October 2019: Returned to specialist training in Otorhinolaryngology at Department of Otorhinolaryngology, Head & Neck Surgery and Audiology, Aalborg University Hospital.

- October 2016 – October 2019: Leave from specialist training.

  PhD fellow at the BEAR project, Department of Otolaryngology, Head and Neck Surgery and Audiology, Aalborg University Hospital and Aalborg University.
- March 2014: Began specialist training in Otorhinolaryngology at Department of Otolaryngology, Head and Neck Surgery and Audiology, Aalborg University Hospital.

- January 2012: M.D., Faculty of Health, Arhus University.

ENGLISH SUMMARY

More men than women have a hearing loss, and the incidence of hearing loss increases with age. In a study from 2010, the Knowledge Center for Hearing Disabilities estimated that 800,000 Danes have disabling hearing loss. The population projection from Statistics Denmark (2018) shows that the Danish population is expected to grow, primarily due to a growth of the oldest portion of the population. This will result in more people in need of treatment for hearing loss in the future. The hearing threshold is the clinical measure most often used to determine whether there is hearing loss and, if so, how severe. This is measured by tone audiometry which tests how intense a given tone must be presented before it can be heard by the patient. Hearing loss can also manifest in the form of difficulty understanding and distinguishing words from one another. This is typically measured by speech audiometry in which a number of words are played and must be repeated by the patient.

The most frequent treatment for hearing loss is the fitting of hearing aids. The majority of treated patients benefit from the use of hearing aids. A hearing aid works by receiving and amplifying sound before sending the amplified sound signal to the ear. Described as such it may seem simple, yet both hearing and sound processing are complex tasks, and there still remains conditions that make successful hearing aid treatment a challenge to obtain across the hearing impaired population. More knowledge about what characterises these patients, who face challenges, as well as knowledge on those who do not, may form the basis of improved treatment in the future.

This dissertation is based on three articles which are based on the first clinical part of the Better hEAring Rehabilitation project (BEAR). BEAR is a five-year project whose goal is to improve hearing aid treatment in Denmark based on clinical research, and if favourable, evidence-based renewal of clinical practice. In the first part of the BEAR project, a database containing information on almost 2,000 patients was established. Patients were included over the course of a year when examined and treated for hearing loss at the Department of Audiology at Odense and Aalborg University Hospitals. The database contains data from questionnaires and audiometric data, as well as data from an objective measurement of the amplified sound delivered to each patient via HAs.

Manuscript 1 reports on quality of life improvements for first-time and experienced hearing aid users after two months of hearing aid use. It was shown that experienced hearing aid users had lower hearing-related quality of life compared to new users before renewing/fitting new hearing aids. Both groups achieved improvement in their hearing-related quality of life after two months of treatment. The overall quality of

life score increased for the group of first-time users, whereas no change was observed for the experienced users.

Manuscript 2 reports on quality of life and speech understanding in patients with asymmetrical hearing loss, that is, a difference in hearing between the right and left ear, compared to patients with symmetrical hearing loss. There is no common standard for defining asymmetrical hearing loss and we therefore used three different definitions: 1) more than 15 dB interlateral difference in pure-tone average (PTA) over four frequencies, 2) more than 15% interlateral difference in word recognition score (WRS) and 3) interlateral difference in audiogram configuration. It was shown that no matter the definition of asymmetrical hearing loss, patients had poorer hearing-related quality of life and spatial hearing before treatment compared to patients with symmetric hearing loss. Two months of hearing aid treatment improved both groups' hearing-related quality of life and speech comprehension, regardless of asymmetry definition.

Manuscript 3 reports on a study of quality of life changes compared to how the hearing aid is fitted, according to the individual patient's hearing loss. The hearing aid amplification in each patient was measured with real ear measurements and compared to a curve expected from a standard prescription, targeted to provide optimal speech understanding. The amplification provided by the hearing aids when a speech signal was played from a loudspeaker was measured and compared to the target curve projected by the standard prescription. It was shown that there was no correlation between self-reported quality of life, and self-reported hearing handicap in relation to the measured gain curve being on or not *on reference*.

Overall, it was found that hearing aid treatment significantly improved patients' hearing-related quality of life. However, some subgroups of patients achieved less improvement than others. Among others, it was shown that patients with asymmetrical hearing had lower self-reported hearing-related quality of life and self-reported hearing handicap than patients with symmetrical hearing. These results will hopefully inspire further research in the field working towards improving health-related quality of life through improved hearing care and rehabilitation.

DANSK RESUME

Flere mænd end kvinder har et høretab, og forekomsten af høretab stiger med alderen. Videnscenter for Hørehandicap estimerede i en rapport fra 2010, at 800.000 danskere har et høretab. Danmarks Statistiks befolkningsfremskrivning fra 2018 viser, at den danske befolkningen forventes at vokse, og at det primært er den ældste del af befolkningen, der bliver flere af. Dette vil resultere i, at stadigt flere vil have behov for behandling for et høretab. Høretærsklen er det kliniske mål der oftest bruges til at måle om der er et høretab og i givet fald hvor stort. Den måles ved en tone-audiometri, som udtrykker hvor kraftig en given tone skal afspilles, før den kan høres. Høretabet kan også vise sig i form af besvær med at forstå og skelne ord fra hinanden og måles ved en taleaudiometri, hvor en række ord afspilles og skal gentages af patienten.

Den hyppigste behandling af en hørenedsættelse sker med høreapparater og langt de fleste, som behandles, har god nytte ved brugen af dem. Et høreapparat virker ved at opfange og forstærke lyden fra omgivelserne for derefter at sende det forstærkede lydsignal ind i øret. Det kan virke simpelt, som det er beskrevet her, men både hørelsen og lydprocessering er komplekse systemer, og der er stadigt forhold som gør høreapparatbehandling svær at vænne sig til for nogle patienter. Mere viden om hvad der karakteriser både de patienter, som har udfordringer og de patienter, som har god effekt af høreapparatbehandlingen, skal danne grundlag for endnu bedre behandling i fremtiden.

Afhandlingen er baseret på den første kliniske del af BEAR (Better hEAring Rehabilitation) projektet. BEAR er et 5-årigt projekt, hvis mål er at forbedre høreapparatbehandlingen i Danmark på baggrund af evidensbaseret klinisk forskning og fornyelse af klinisk praksis. I den første del af BEAR projektet blev der etableret en database med information om knap 2000 patienter som igennem et år blev undersøgt og behandlet på Audiologisk Afdeling på Odense og Aalborg Universitetshospital. Databasen består af spørgeskema- og audiometri data, samt data fra en objektive måling af hver enkelt patients høreapparatforstærkning af et talesignal. Forstærkningen blev målt i patientens øre med den enkelte patients høreapparat isat.

Manuskript 1 omhandler livskvalitetsforbedringer ved nye og erfarne høreapparatbrugere efter to måneders brug af høreapparater. Det blev vist, at erfarne høreapparatbrugere havde lavere hørerelateret livskvalitet før fornyelse af deres høreapparater sammenlignet med nye brugere før behandling. Begge grupper opnåede forbedring af deres hørerelaterede livskvalitet efter to måneders behandling. Den samlede livskvalitet score steg for gruppen af nye brugere, hvorimod der ikke blev set en signifikant ændring for den erfarne gruppe.

Manuskript 2 omhandler livskvalitet og taleforståelse hos patienter med asymmetrisk høretab, altså forskellige høretab på hhv. højre og venstre øre, sammenlignet med patienter med symmetrisk høretab. Der findes ikke en universel standard for hvordan asymmetrisk hørelse defineres og vi anvendte derfor tre forskellige metoder til definere asymmetri mellem venstre og højre øre: 1) forskel på >15dB i ren-tone-gennemsnittet (PTA) på fire frekvenser, 2) >15% forskel i ord-genkendelse (WRS) og 3) forskel i konfiguration af hørekurve. Det blev vist, at uanset hvordan vi definerede asymmetrisk hørelse havde patienterne dårligere høre-relateret livskvalitet sammenlignet med patienter med symmetriske høretab. De havde ligeledes dårligere rum- og retningshørelse. To måneders høreapparatbehandling forbedrede begge gruppers høre-relaterede livskvalitet og taleforståelse uanset definitionen for asymmetri.

Manuskript 3 omhandler en undersøgelse af livskvalitets ændringer sammenholdt med hvordan høreapparatet er tilpasset den enkeltes høretab i forhold til et standard tilpasningsrationale. Høreapparatets forstærkning, af et afspillet talesignal blev målt i hver enkelt patients øre og sammenlignet med den forstærkning, der ifølge et valideret rationale blev fremskrevet, at patienten havde behov for, for at opnå bedst mulig taleforståelse. Det blev vist at der ikke var en sammenhæng imellem livskvalitet og om høreapparatets forstærknings indstillinger var tæt på eller længere væk fra en standards forstærkningskurve.

Overordnet blev det vist at høreapparatbehandling af høretab forbedrede patienternes hørerelaterede livskvalitet. Dog opnår nogle patienter større forbedring end andre. Det blev blandet andet vist at patienter med asymmetrisk hørelse havde lavere høre-relateret livskvalitet og taleforståelse end patienter med symmetrisk hørelse. På trods af en generel forbedring af høre-relateret livskvalitet og taleforståelse af hele studiepopulationen er der stadig patienter, der opnår mindre udbytte end andre. Forhåbentlig kan disse resultater inspirere yderlig forskning inden for området for fortsat at arbejde mod en bedre høreapparatbehandling.

ACKNOWLEDGEMENTS

To Sabina Storbjerg Houmøller, my closest colleague at the BEAR project with whom the database was compiled. You shared your knowledge on technical audiology and quickly prepared me to manage the tasks in a field relatively unknown to me. Thank you for the collaboration throughout the project and support along the way.

To Michael Gaihede, my main supervisor for this dissertation, who made me aware of the position at the BEAR project and encouraged me to apply. Thank you for the close collaboration and support throughout my PhD, especially during the last few months. I hope for future collaboration both in the clinic and academically.

To Henrik Jacobsen, Head of the Department of Otolaryngology, Head and Neck Surgery, Aalborg University Hospital. Thank you for being my supervisor during my first years as an ENT registrar and for supporting me during the process of this PhD. Through our many conversations you helped me see the strength of diversity and smooth some sharp edges. I hope for future collaboration.

To Dorte Hammershøi, my co-supervisor, initiator and project manager of the BEAR project. Your knowledge, overview and commitment is inspiring. Thank you for your guidance and being available for discussions, no matter how small my questions. Thanks for caring.

To Jesper Hvass Schmidt, my co-supervisor and BEAR work package leader. Your extensive scientific and clinical knowledge is admirable and I feel grateful to have had the opportunity to collaborate and learn from you. Thank you for your patience and your great commitment.

To Dan Hougaard, Gérard Loquet, and all my colleagues at the BEAR project. Thank you for creating an environment with the space for professional disagreement and working towards a common goal. It has been a privileged to be a part of this unique project and getting to know you all. I look forward to further cooperation.

To my parents who taught me curiosity, work ethic and persistency; the latter was tested in this PhD, but ultimately endured. Thank you to my friends and family for your support.

To Mads, whose limit of patience I have yet to find. Your support and unconditional love and care has played an invaluable role in the process of this PhD and the completion of this dissertation. ***

LIST OF MANUSCRIPTS

Manuscript 1

Wolff, A., Houmøller, SS., Hougaard, D., Gaihede, M., Hammershøi, D., Schmidt JH. Health-Related Quality of Life in Hearing Impaired Danish Adults Before and After Hearing Aid Rehabilitation.

Manuscript 2

Wolff, A., Schmidt JH., Houmøller, S., Hougaard, D., Loquet, G., Narne, V., Hammershøi, D., Gaihede, M. Significance of Asymmetrical Hearing Loss on Self-Reported Outcomes in Hearing Aid Treatment.

Manuscript 3

Wolff, A., Schmidt JH., Houmøller, Rye, P., Narayanan, SK., Hougaard, D., S., Loquet, G., Narne, V., Hammershøi, D., Gaihede, M. Comparison of Real-Ear Hearing Aid Amplification and Self-Reported Outcomes.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

15D	15-Dimensional Instrument, Quality of Life Questionnaire
15D-3	Hearing Related Quality of Life (3^{th} question of the 15D)
AAUH	Aalborg University Hospital
AHL	Asymmetrical Hearing Loss
dB	Decibel
HA	Hearing aid
HI	Hearing Impairment
HL	Hearing Loss
HRQoL	Health-Related Quality of Life
HUI3	Health Utilities Index Mark 3
IEC	International Electrotechnical Commission
IOI-HA	International Outcome Inventory for Hearing Aids
ISTS	International Speech Test Signal
kHz	Kilohertz
OALYs	Quality Adjusted Life Years
OUH	Odense University Hospital
PTA	Pure Tone Average
REM	Real Ear Measurement
RSD	The Region of Southern Denmark
SD	Standard Deviation
SHL	Symmetrical Hearing Loss

SNHL	Acquired Sensorineural Hearing Loss
SPL	Sound Pressure Level
SSQ-12	Speech, Spatial and Quality of Sounds Questionnaire (Abbreviated)
THI	Tinnitus Handicap Inventory
WHO	World Health Organization
WRS	Word Recognition Score

CHAPTER 1. INTRODUCTION

The WHO estimates (2008) that 5.3% of the world population have a disabling hearing loss (HL). In Europe 30% of men and 20% of women present a slight to severe HL beyond 70 years of age. This proportion grows to 55% of men and 45% of women beyond 80 years of age (Gates and Mills, 2005). Globally, it makes adult-onset HL the 15th leading cause of disease and the second leading cause of years lived with a disability (WHO, 2017).

The percentage of the Danish population affected by a HL is not known as no national clinical database exist. The latest report on HL in Denmark is from 2006 and it was then estimated that 800.000 Danes had disabling HL (Christensen, 2006; Bengtsson and Røgeskov, 2010). Higher life expectancy is one of the reasons for the continued growth of the general population. As a result, the proportion of the population with disabling HL is also bound to increase.

Being able to hear and communicate is an import aspect of human life, thus for patients experiencing HL the consequences can be extensive. The ability to communicate is often unaffected in the early onset of HL as the decline in hearing may develop slowly and listening strategies may be obtained unnoticeably. Over time, HL progresses and can cause exhaustion from trying to hear speech in difficult listening environments. As a consequence of not being able to take an active part in conversations at social gatherings, HL has a high risk of having a negative impact on social interaction (e.g., isolation) and mental health (e.g., anxiety and depression) (Dalton *et al.*, 2003; Ishine, Okumiya and Matsubayashi, 2007).

There is a subtle difference between having a hearing impairment (HI) and experiencing HL. The term HI entails having hearing which is different from what is understood to be normal hearing regardless of point in time, where the HI arose. The term HL, on the other hand, implies that normal hearing was initially present, in order to be able to experience a loss. The reason for distinguishing between the two is the fact that losing one's hearing has greater consequences on, for example, social interactions then having an innate HI or prelingual HI (Fellinger *et al.*, 2005). Hence the term HL is the most appropriate to use in this dissertation.

CHAPTER 2. BACKGROUND

2.1. THE BETTER HEARING REHABILITATION PROJECT

The Better hEAring Rehabilitation (BEAR) project is a five-year project that started in the beginning of 2016 as a collaboration between partners engaged in different areas of the Danish HA field. The partners involved in the project included three university hospitals, three universities, three Danish HA manufactures and a Danish government-approved research and technology service.

Through this unique collaboration of partners, the probability of the results being directly beneficial to the patients is highly likely. The field of HA is well studied, but there is still potential for more results from the field to be translated into changes and improvements to the clinical practise. The aim of the BEAR project is to achieve better HA rehabilitation, through studies of the clinical practise related to HA fitting. The project is divided in three phases: 1) Clinical database and improved HA-outcome assessments, where among others documenting current clinical practices by gathering data on HA users, 2) validation of new strategies and proposals of revised standards. Apart from the database being used as a reference in the other phases of the project, it is also used to study various epidemiological contexts.

2.2. HEARING LOSS

The auditory sense is understood as the ability to perceive and decode sound waves through the ear canal, the middle ear and the cochlea, and further through the auditory vestibular nerve to the superior temporal gyrus of the temporal lobe, where the primary auditory cortex lies. A problem in any one of these structures can lead to HL, which can present in a variety of forms.

Clinically, HL can roughly be described in two ways: 1) as the tone threshold and/or 2) the speech-reception threshold. The tone threshold is an expression of a patient's ability to hear different pure tone frequencies at the lowest possible sound pressure. The results of the test are expressed in a pure tone audiogram in dB HL, and does not take the patient's hearing skills or central processing ability into account. The speech-reception threshold is a measure of the ability to discriminate and understand speech. The two ways of measuring HL do not necessarily follow from one other. A patient can have an audiogram-determined HL without the coexistence of a discrimination disability, and vice versa (Vermiglio *et al.*, 2012). The disagreement between the audiogram and the degree of difficulties the patient experience is one of the aspects which pose a challenge for hearing rehabilitation. The audiogram has been, and still is, used as the "gold standard" for HL. However, the audiogram is a poor indicator of speech recognition, especially for speech in noise (Blandy and Lutman, 2005), which is the primary complaint of HA users.

Going into further details, the audiogram is used to classify HL into three types: sensorineural, conductive and mixed HL. The cause of sensorineural HL can be present in the inner ear, the cochlea or the related structures. The full explanation of what causes the sense of hearing to decline is still unknown, as the interplay between the different structures is very complex. Conductive HL is a consequence of more mechanical nature and a linear amplification of sound via a HA can in some cases alleviate the HL, as the nerve leading the sound input and central processing is unaffected. With pronounced conductive HL, surgery or fitting a bone-anchored hearing aid can be an alternative if a conventional HA is insufficient. As it is possible to have multiple sites of lesions, a mixture of sensorineural and conductive HL is also a possibility. The treatment depends on which lesion dominates the HL. A combination of surgery and HA treatment might also be a solution.

The reason for a lesion in the hearing-process can further complicate the matter. The lesion can be present at birth or be acquired due to traumas and/or ageing. The most prevalent type of HL in adults is acquired sensorineural HL (SNHL), which primarily stems from structural decay in the inner ear, the cochlea. SNHL is one of the few chronic conditions for which there is no effective medical or surgical treatment. However, the HL needs to be acknowledged by the patient before treatment can be considered.

Untreated HL can have widespread consequences for the patient. Even a mild degree of HL can cause social, emotional and communication difficulties and thus a reduced health-related quality of life (HRQoL). The first choice for hearing rehabilitation is often HAs and the derived symptoms of HL can to some extent be alleviated with HA. Hearing rehabilitation can result in small but clear improvements in social, emotional, communication and cognitive functions (Mulrow *et al.*, 1990). In recent years, HA technology has steadily improved, with increased benefits for people with HL (Sorri *et al.*, 2001; Kaplan-Neeman *et al.*, 2012).

2.3. HEARING AID REHABILITATION

The first choice for HA rehabilitation for patients with SNHL is conventional HAs, which deliver amplified sound to the ear canal. The aim of rehabilitation is to reduce the impact of HL on the patient's life (Boothroyd, 2007). The history of HAs goes back hundreds of years, from the first ear trumpets in the nineteenth century to the digital HAs we use today, and the development of listening devises is still ongoing. Various signal processing techniques are used in HAs. When the digital HA was introduced, more signal possibilities became available. The HAs fitted today are advanced amplifiers which improve the likelihood of the speech signal being optimally delivered to the auditory system and prevent intense sounds by compression. Although, compression causes distortion, troublesome distortion is no longer a significant factor in HA signal processing (Bentler and Duve, 2000). The use

of wide-dynamic range compression has provided the opportunity of a uniform access to the softest and loudest speech cues (William Yund and Buckles, 1995; Franck *et al.*, 1999). The directional microphone has been used to improve the signal-to-noise ratio in certain communication settings (Ricketts and Galster, 2008).

A HA must be fitted according to the specific HL in order to provide maximal benefit to the user. The fitting consists of two parts: prescription and fine-tuning. The prescription is an algorithm is designed to maximise speech intelligibility by providing optimum amplification across frequencies based on the patient's hearing threshold (Mueller, 2005). There are at least two validated and commonly accepted prescriptive fitting methods: the National Acoustic Laboratories Non-Linear version 2 (NAL-NL2) (Keidser *et al.*, 2011), and the Desired Sensation Level version 5 (DSLv5) (Scollie *et al.*, 2005). While some manufacturers (such as Bernafon, Siemens and Unitron) recommend using established prescription procedures such as NAL-NL1/2 and DSL as a baseline for fitting their devices, others have introduced their own proprietary fitting algorithms (such as Oticon, Phonak, GN ReSound and Widex) (Keidser, Brew and Peck, 2003). Fitting is often followed by a fine-tuning, which is an iterative process based purely on subjective feedback from the user. Based on clinical experience, there is a specific challenge regarding first-time users of HA, as they tend to trade functionality for a more comfortable amplification level.

2.4. HEALTH-RELATED QUALITY OF LIFE

Alongside the development of better treatments and increased healthcare costs, not only in audiology care but throughout the medical system, new outcome measures have developed. One of the reasons for the development of new outcomes measures is due to the continuing rise in healthcare expenses, both in total but also as a percentage of gross national product (OECD and European Union, 2018).

In other fields of human pursuit, e.g. production of food or private services, the success is measured by its profit. However, the measure for success of a treatment is debatable; and when it comes to comparing different types of treatments, including across medical fields, it becomes even more difficult. We do not have to look back more than 70 years to find a time, where advanced treatment was unavailable and the discussion of whether or not the treatment is worth the cost did not exist. As medical science developed, the need for the systematic evaluation of the benefits and effectiveness of treatment has emerged. Concurrently, the WHO define health as *"a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity".*

In the late 1950s there was a shift towards the emphasis of a person's capacity and ability to perform daily activities, well-being and quality of life (QoL). The term health-related quality of life (HRQoL) has been introduced to describe the aspects of QoL that excludes aspects not related to health, for example cultural, political or

societal attributes (Ferrans *et al.*, 2005). HRQoL is a multidimensional concept which covers patients' perceptions of his or her physical, emotional, social and cognitive functions. HRQoL emphasises the personal perception of the quality of one's life based on personal expectations. The uniqueness of a person's own experience of how the condition emerges suggests that two people with the same disease can judge their HRQoL very differently (Ferrans *et al.*, 2005).

2.4.1. DISEASE-SPECIFIC QUESTIONNAIRES

Numerous questionnaires exist to measure and document the improvement of HA benefits and HRQoL. The questionnaires that focus on a specific illness or intervention are referred to as disease-specific measures. They have been developed to measure health status in a clinical investigation, for example when evaluating one treatment for a disease against an alternative treatment. Several questionnaires address the functional HA benefit, satisfaction and HRQoL within a single questionnaire, such as the International Outcome Inventory of Hearing Aids (IOI-HA)(Cox and Alexander, 2002). Another questionnaire often used in clinical and research-related contexts is the short form of Speech, Spatial and Qualities of Hearing Scale (SSQ12) (Noble *et al.*, 2013). The difference between the two is the general character of the IOI-HA, whereas the SSQ12 examine the hearing disability in greater detail. These specific questionnaires have been chosen as tools for the collection of data for the BEAR database, as they are widely used in both Danish and international contexts and therefore allow for the possibility of comparisons with previous studies.

The IOI-HA was developed as a supplement rather than a stand-alone instrument with the intension to provide directly comparable data on an international level. It has become popular in recent decades as it has a low patient and clinician burden, and it is easy to interpret. Additionally, it has been designed to minimise literacy and cognitive demands, and it is therefore widely applicable (Cox, Alexander and Beyer, 2003). It consists of seven questions addressing the main dimensions of HA treatment. A limitation of the IOI-HA is that it does not provide specific information about hearing performance in different listening situations and is therefore used as a supplement in this study (Hickson, Clutterbuck and Khan, 2010).

A questionnaire designed to provide the details missing from the IOI-HA is the SSQ12. It comprises 12 questions grouped in three sections and is used to measure several aspects of hearing ability, such as speech comprehension in quiet and noisy environments, localisation of sound, segregation and listening effort. Each question is answered on a scale from 0–10, where 10 means being able to perform perfectly in the situation in question. The questionnaire is valid for self-administration methods (Singh and Pichora-Fuller, 2010) and has been widely used for assessment in various

studies (Noble and Gatehouse, 2004; Dumper *et al.*, 2009; Olsen, Hernvig and Nielsen, 2012).

Being able to compare results within hearing research is one aspect, though in order to be able to compare interventions across medical fields, measuring overall health status is required. For this purpose the generic HRQoL questionnaires are used.

2.4.2. GENERIC HRQOL QUESTIONNAIRES

Most generic questionnaires include items related to the major health domains of physical, social and mental health, though they differ in the level of detail which they assign these dimensions or of questions pertaining to these domains. The absence of hearing-related questions on most commonly used health status questionnaires has made it difficult for researchers to ascertain the effect of HAs for adult-onset hearing impairment. The most frequently used generic HRQoL questionnaires in hearing research include the 36-item Short Form Health Survey (SF-36) (Scoggins and Patrick, 2009), the EuroQoL 5-dimensions (EQ-5D) (EuroQoL Group, 1990) and the Multi-Attribute Health Status Classification System (HUI-3) (Horsman *et al.*, 2003).

It is not an essential requirement that a generic questionnaire include a question on hearing in order to measure improvements due to interventions directed at HL. Nonetheless, when such a question is not included there arises concern whether the generic HRQoL questionnaire is sensitive to interventions which improve hearing (Summerfield and Barton, 2019). Two of the generic HRQoL questionnaires that do not include a question on hearing is the SF-36 and EQ-5D. It is concluded in a review of previous HA research that the SF-36 appears to lack responsiveness to the effects of interventions for adult onset HL (Bess, 2000) and thus that an alternative should be used in the case of hearing research. With regard to the EQ-5D, a study evaluating its sensitivity in hearing research concluded that the EQ-5D should be used to evaluate interventions intended to improve tinnitus, though it lacked sensitivity to measure impaired speech reception (Summerfield and Barton, 2019).

The HUI3 generic HRQoL questionnaire has been widely used in the USA, the UK, Australia and Canada, where it was evolved. The HUI3 has been evaluated in terms of its responsiveness to HA interventions and has also been used effectively in measuring HRQoL improvements among cochlear implant recipients (Wyatt *et al.*, 1996; Francis *et al.*, 2002). The HUI3 has been translated into Swedish yet its use in the Scandinavian countries is limited and it has not yet been translated into Danish or been validated.

The 15 dimension-instrument (15D) has been translated into Danish and was validated through the creation of utility weights based on a subset of the general Danish population (Wittrup-Jensen and Pedersen, 2008). Although differences exist, the HUI3 and 15D share many similarities. The use of the 15D in hearing research is

limited, but it has been shown to have a sensitivity toward hearing-related interventions (Niemensivu *et al.*, 2015).

2.4.3. 15D-INSTRUMENT

The 15D is a generic HRQoL questionnaire developed in Finland for use in socio-economic studies to evaluate the cost-benefit of a treatment or intervention. The 15D consist of 15 questions/dimensions which have an impact on HRQoL. The 15D includes questions on Mobility (move), Vision (see), Hearing (hear), Breathing (breath), Sleeping (sleep), Eating (eat), Speech (speech), Excretion (excrete), Usual activities (uact), Mental function (mental), Discomfort and symptoms (disco), Depression (depr), Distress (distr), Vitality (vital) and Sexual activity (sex). Each dimension is answered by the patients selecting one of the five levels that best describe his/her present health status. The 15D provides both a profile and total HRQoL score based on national utility weights/utility measures.

Like the HUI3, the 15D assess HRQoL through the use of utility measures. Utility measures refer to the preference of an individual or population for a particular health state (Bennett and Torrance, 1996). As part of the 15D, the utilities are measured with a scale ranging from 0–1, where 0 designates death and 1 designates perfect health. This approach makes is possible to compare the effect of disease and interventions on HRQoL within and across disorders.

The utility measures/weights are derived from the validation process, where the 15 domains are ranked according to their impact on HRQoL, from most to least impact. The order of dimensions may vary due to cultural differences across national borders, hence national validation and utility scores are recommended, when making use of the 15D (Badia *et al.*, 2001; Wittrup-Jensen and Pedersen, 2008). Not only are the 15 dimensions themselves ranked, but the five levels in each of the dimensions are also ranked. The within-dimension ranking is used when forming a profile, whereas both the within-dimension and the between-dimension rankings are used, in the total 15D score (Wittrup-Jensen and Pedersen, 2008).

For example, a person is asked to select one of the five descriptors that best represent his or her hearing and hearing related QoL (15D-3, Table 2.1). Each descriptor (1 to 5) is associated with a different utility weight, for example for 15D-3: 1 = 1.0; 2 = 0.7734; 3 = 0.5439; 4 = 0.2969 and 5 =0.1621 (Table 2.1).

Level	Description	Utiliy weight
1	I can hear normally, i.e. normal speech (with or without a hearing aid).	1.0
2	I hear normal speech with a little difficulty.	0.7734
3	I hear normal speech with considerable difficulty; in conversation I need voices to be louder than normal.	0.5439
4	I hear even loud voices poorly; I am almost deaf.	0.2969
5	I am completely deaf.	0.1621

Table 2.1 Utility weights for the various health states for the hearing dimension (15D-3). The utility weights presented are the Danish weights with the English description. The table is adapted from the 15-Dimension instrument (www.15d-instrument.net/15d/) and the Danish validation of the 15D questionnaire by Wittrup-Jensen and Pedersen (2008).

In the analysis of the 15D responses, utilities are measured for the multiple domains and a summary measure is calculated to provide an overall score. These utility scores allow for an estimation of quality-adjusted life years (QALYs) and the further application of these can be used in the estimation of cost-utility ratios for various diseases.

2.4.4. QUALITY-ADJUSTED LIFE YEARS (QALYS)

With the competing demands for resources across the medical field, the role of economic evaluation in healthcare is to provide information on relative costs and benefits to support decision makers regarding how to prioritise available resources. A particular approach to economic evaluation, cost-utility analysis, has become a key analytical tool for health economists. Within cost-utility analysis, benefit from treatment is measured in terms of QALYs. The QALY is a metric that combines information on both the duration and quality of life following treatment. Since the traditional measures of HRQoL, using generic or specific instruments, are of limited use in economic evaluations, it is necessary to include a preference-based utility measure in order to be able to make these evaluations (Drummond *et al.*, 2015). In the past decade a growing number of studies have used these economic evaluations in hearing research to document the fact that patients with untreated HL have lower HRQoL compared to a standardised population, and that HA treatment can significantly improve HRQoL. Hence, justifying the costs involved in the treatment. (Lutman, Brown and Coles, 1987; Mulrow *et al.*, 1990; Swan, Guy and Akeroyd, 2012).

2.5. OBJECTIVE MEASURE

Determining the benefit of HA treatment, the terms validation and verification are often used (Jorgensen, 2016). Validation measures refer to outcome measures designed to assess whether the HA is of benefit to the patient, while verification measures primarily focus on ways to confirm that the gain from the HA matches the prescribed target. Common to both ways of evaluating HA benefits is the aim of ensuring the best possible acoustic information for appropriate speech communication. Many speech tests have been developed in an attempt to objectively measure the effectiveness of HA treatment, for example the word recognition test (Causey *et al.*, 1983; Elberling, Ludvigsen and Lyregaard, 1989) and the hearing-in-noise test (Nilsson, Soli and Sullivan, 1994). However, although these tests provide a measure of change in audibility after HA treatment they depend on the patients' subjective response and do not validate whether the amplification of sounds is adequate. Further, research has found that these tests lack real-world validity, while clinicians found a use of a functional gain measure using various prescriptive approaches (Abrahamson *et al.*, 2005).

2.5.1. REAL EAR MEASUREMENT

An increasing use of real ear measurement (REM) among audiologist has been reported (Aazh and Moore, 2007), as it can be used in the verification of a HA fitting. It is an objective measure that ensures that the HA operates appropriately by analysing the output of the HA through probe microphone measurements. REM is the valid manner in which to verify the actual sound delivery of a particular HA used in a particular patient's ear canal. The use of REM in Denmark is limited and no national clinical recommendation or guideline currently exists. In the fast developing HA industry of today, the need for verifying HA-amplification seems appropriate, as HA fitting with proprietary prescriptions is becoming more common. No recent national inventories on the use of prescriptive methods exits, but in the BEAR database 97% of the patients had their HAs fitted according to the proprietary fitting. The REM method is thoroughly described in the method section of this dissertation.

2.6. CLINICAL RESULTS OF PREVIOUS STUDIES

For many decades the interest in developing and documenting the effect of modalities for treating HL has been growing. The result is that the amount of instruments used to investigate HA benefits is numerous. The coordinating work regarding HRQoL research and HA treatment has not yet been successful, although attempts have been made (Shield, 2019). In general, the benefits of HAs have been well studied and many different instruments have been used. The results obtained are heterogeneous, though they provide a clear picture that not only is HA treatment justified but also that

untreated HL has extensive individual and socio-economic detrimental consequences (Shield, 2019).

2.6.1. HEARING AID BENEFIT AND HRQOL

Several studies have evaluated HA outcomes with hearing-specific measures which are highly responsive to interventions targeting HL. Most of the studies have shown a strong reduction in the emotional and social impacts of HL after HA treatment. In a study using the disease-specific questionnaire Hearing Handicap Inventory for Adults (HHIA) (Newman *et al.*, 1990) to investigate the outcomes of HA fitting they found a positive impact on HHIA scores three months after HA fitting (Stark and Hickson, 2004). Furthermore, they found a relationship between the change in HHIA score for the participants with HL and two factors: degree of HL and reported use-time of HA. Patients with a speech frequency pure-tone average HL (0.5, 1 and 2 kHz) greater than 35 dB HL reported greater reduction (the lower the HHIA score, the less the disability) when compared to the reduction found when the speech frequency PTA HL where less than 25 dB HL. The finding directly relates to the fact that those with greater HL experience more hearing problems before HA treatment and therefore have a greater potential for an improvement after treatment. For the relationship between HHIA score and use-time of HA, the improvement was greater for those patients who wore their HAs more (Stark and Hickson, 2004). Similar significant improvement was found in the emotional and social domains using the same or other disease-specific questionnaires (Dalton *et al.*, 2003; Chisolm *et al.*, 2007; Ishine, Okumiya and Matsubayashi, 2007). The implication of HL on more than audibility is further supported by a study which found an association between HL and social isolation and depression (Dawes *et al.*, 2015).

Research regarding generic HRQoL is varied (Chisolm *et al.*, 2007), but the results regarding the reduction of depression or/and anxiety have been reproduced using generic HRQoL questionnaires (Mulrow *et al.*, 1990; Joore *et al.*, 2002). Additionally, reduction in the subscales of general health and vitality as a result of HA treatment have been found (Stark and Hickson, 2004), measured three months after fitting, using the Short Form-36 (SF-36) (Ware and Sherbourne, 1992).

Common to hearing research is the fact that is has been undertaken by studying first-time users of HAs. One of the few studies that includes experienced HA users (Cox, Johnson and Xu, 2014) found improved HRQoL after one month of treatment, though they report their findings in the context of advanced HA versus basic HA technology. Unfortunately, they do not report separate results for the two groups of HA experience. As it is custom in Denmark to renew HAs when the warranty on the HAs expires after four years, it is highly relevant to evaluate whether the treatment up to the point of HA renewal is optimal. There is a lack of research investigating for how long the initial positive impact of HA lasts, as most studies end their observation no

within one year after HA fitting. The impact of HA experience on HRQoL is discussed in Manuscript 1 in the thesis.

Other groups of patients known to experience low benefits from HAs are patients with bilateral asymmetrical HL (AHL) and patients with unilateral HL (UHL). The hypothesis that asymmetrical hearing has a negative consequence on hearing performance is well investigated in the literature. However it was not until the mid-60's that Giolas and Wark (1967) turned research attention towards the difficulties experienced by patients with asymmetrical hearing in complex listening situations. They write that "*it has become increasingly apparent that a special clinical program must be developed to meet the specific needs of a person with unilateral hearing loss*". In the years leading up to this research, empirical evidence had made clinicians increasingly aware of the problem (Harford and Barry, 1965). Thus, it is now well established in the literature that the absence of balanced binaural hearing makes sound localisation and speech understanding in noise a challenge for both individuals with normal hearing and individuals with HL (Häusler, Colburn and Marr, 1983; Peissig and Kollmeier, 1997; Firszt, Reeder and Holden, 2017). Further studies have shown that the consequences of having AHL includes the disturbance of communication and is associated with increased effort during real-life listening conditions (Wie, Pripp and Tvete, 2010; Dwyer, Firszt and Reeder, 2014). The majority of research on the significance of asymmetrical hearing include patients with UHL, while fewer studies investigating AHL exist.

A 2004 study (Noble and Gatehouse) examined the effect of AHL, defined as a interlateral difference of PTA (0.5, 1, 2 and 4 kHz) more than 10 dB. They found that patient with AHL had significantly poorer spatial hearing when self-assessed using the SSQ compared to patients with symmetrical HL (SHL). The negative effect of AHL/UHL on spatial hearing has been shown in previous clinical studies, although often in the context of post-surgery for vestibular schwannoma (Humphriss *et al.*, 2004; Douglas *et al.*, 2007). Later studies also support this conclusion, as Olsen, Hernvig and Nielsen (2012) found that self-reported sound localisation and estimation of distance from sources were rated worse when a patient has UHL. The consequences of AHL is discussed in Manuscript 2 in this dissertation.

Based on existing research results, there is little if any doubt that hearing rehabilitation with HAs in general is of considerable benefit to patients with HL. There are, however, patients who do not experience the positive effects of HA treatment. In 2011, it was estimated the 20% of the HAs distributed in Denmark ended up not being used (Parving, 2011). It is a rough estimate and the number reported by others varies from 4.7% (Hougaard and Ruf, 2011) to 24% (Hartley *et al.*, 2010). Many studies have examined use time of HAs, including a 2012 systematic review (Perez and Edmonds, 2012). They found a lack of consistency in the way that use of HAs was assessed and categorised. Nonetheless, it is generally well known that there are patients not

enjoying the intended benefit from their HAs, though the reasons are to a large extend unknown.

CHAPTER 3. MATERIALS AND METHODS

3.1. PARTICIPANT

This study included a large number of patients referred for HA treatment at the involved clinics. In the Region of Southern Denmark a collaboration with the local ENT practitioners was established. Patients were informed of the project and invited to participate during their visit to their local ENT. Consent to participate was noted in the referral letter to the Department of Audiology, Odense University Hospital (OUH) and patients were included in the BEAR database. In the North Denmark Region, patients followed the normal flow of referral from private ENT practitioners to the Department of Audiology, Aalborg University Hospital (AAUH) (manuscript 1). Patients booked as first-time users of HAs were sent a digital invitation to the study 14 days prior to their hearing examination. Recruitment at both sites started in January 2017 and the last follow-up was in June 2018. A total of 1961 patients were included.

Patients were accepted into the study if they met the following criteria:

- Adults (≥18 years)
- Had a serviceable hearing loss
- Were able to read and understand Danish
-
- Patients were excluded if they:
- Were candidates for cochlear implants or bone anchored hearing aids
- Were candidates for other surgical treatments of HL (e.g. otosclerosis)
- Had malformations of the auricle and/or inner ear
- Had tinnitus without a concurrent clinical diagnosed HL

Patients made a free and informed choice before consenting to participate and signed a written consent form.

3.2. THE CLINICAL DATABASE

All studies in this thesis are based on the data collected as a part of the first clinical study of the BEAR project. Based on the time allocated for data collection and power calculations, the goal was to recruit 2,000 patients for the database. The database should serve as a base for investigating various hypotheses regarding patients with HL who received HA treatment. The database is to hold information on general patient characteristics and quantitative survey data in combination with audiological data. The comprehensive database should make the categorisation of relevant subgroups possible. Identifying subgroups experiencing a low benefit of HA and their characteristics was of particular interest. For the survey part of the database, a set of five international well-known and used questionnaires were agreed upon, alongside general health-related questions. The database was built using the browser-based Research Electronic Data Capture (REDCap) platform (Harris *et al.*, 2009) hosted at OPEN, Region of Southern Denmark. A study record was created using the patients' name and civil registration number (CPR number). REDCap allowed us to electronically distribute unique links to every patient included in the project via a digital mail box (E-boks) and therefore their answers were directly entered into the database. Features of the REDCap system managed the distribution of the questionnaires based on the patients' appointments at the clinics.

The audiometric data was collected using AuditBase, with the audiometry software OTOsuite (Otometrics), Titan and Affinity (Interacoustics) and HA fitting software (e.g. Genie from Oticon, Compass GPS from Widex and Resound Smart Fit from GN ReSound). All software is compatible with the NOAH System, which makes integration possible across brands and ensures direct access to audiometric and HA fitting data. During data collection the audiometric part of the BEAR database was organised into two different modules, as audiometric data was distributed between the OUH and AAUH. Close collaboration between the two clinics minimised the differences in audiometric procedures.

3.3. STUDY TIMELINE

Patients were referred to OUH or AAUH by their private ENT practitioners for further hearing examinations and HA fitting if favourable. Patients were sent a link to the baseline questionnaires two weeks prior to their hearing examination (Figure 3.1).

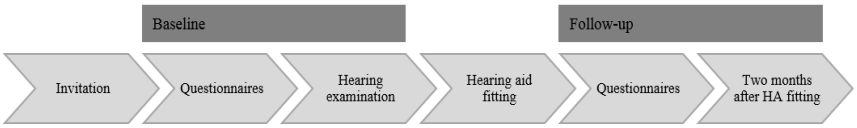

Figure 3.1 Study timeline

After the first visit, patients were scheduled for HA fitting approximately six weeks after the first visit. Before leaving their HA fitting appointment they were booked for a subsequent follow-up visit after two months. Two weeks before the follow-up visit, follow-up questionnaires were distributed. At the follow-up visit a REM was performed before registration of the HA type, model, ear-plug/mould, fitting rationale, average use time of HA and program use in REDCap. If the patients expressed a dissatisfying physical fit or problems with sound qualities in the HA, adjustments were made. In case of adjustments the REM procedure was repeated.

3.4. MEASURES

3.4.1. AUDIOMETRY

An audiometric examination was performed according to current clinical practises and was initiated with an otoscopy to secure an open ear canal and the status of the tympanic membrane. At the first visit several standard measurements were taken by trained audiology assistants; all audiological tests were done using a Madsen Astera 2 (Type 1066) audiometer, calibrated yearly, and with AC Headset TDH39 headphones in AAUH and insert earphones ER-3A in OUH.

Unaided air conduction (AC) audiometry was performed using the ascending method (ISO 8253) for both ears with pure tones at standard audiometric frequencies (250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000 and 8000 Hz). The 750, 1500 and 6000 Hz frequencies were tested only when the neighbour octave frequencies provided a threshold of more than 20 dB apart (the 20 dB rule). The contralateral ear was masked using narrow band noise whenever the BC threshold was ≥35 dB apart. The measurement started at 50 dB HL unless a more ideal level was selected based on the referral audiogram.

Bone conduction (BC) audiometry was performed with a bone stimulator at standard audiometric frequencies (500, 1000, 2000, 3000 and 4000 Hz). If the difference between AC and BC thresholds were ≤10 dB then the BC thresholds were completed unmasked for the best hearing ear and also indicated on the audiogram for the best hearing ear. Masking of the contralateral ear was done using narrow band noise whenever the difference in threshold between AC and BC was ≥10 dB.

Unaided speech reception threshold (SRT) was measured separately for each ear using headphones in quiet. If indicated by the AC, masking was applied. The first threshold reached, where two digits out of a triplet were correctly heard, determined the level of the SRT (DANTALE) (Elberling, Ludvigsen and Lyregaard, 1989).

The unaided word recognition score (WRS) was assessed in quiet for each ear (contralateral ear masked when possible) using the DANTALE word test (Elberling, Ludvigsen and Lyregaard, 1989) and reported in percent, with 100% signifying that all words were correctly repeated. WRS was measured at 30–40 dB above pure tone average (PTA; average of hearing sensitivity at 500, 1000 and 2000 Hz), depending on the hearing status, but at a minimum of 70 dB HL.

The DANTALE word test consists of eight lists of 25 phonetically balanced, monosyllabic words (lists 1 and 2 are used most often). In cases where the standard WRS was 20% or less a detailed S-curve was performed to uncover potential sound pressure levels with better WRS.

At AAUH, wideband tympanometry was performed using Titan Suite IMP440 Impedance Wide Band module (Interacoustics). Via a probe placed in the patient's ear canal, 21.5 clicks per second were played at an intensity of 100 dB SPL (65 dB: normal HL) while the ear canal pressure changed from +250 daPa to –350 daPa with a pump speed of 100 daPa/second (1 daPa = 10 Pascal). At OUH, conventional tympanometry was performed using standard equipment to estimate compensated static admittance and tympanometric width, peak pressure and ear canal volume. A probe tone of 226 Hz was presented in the ear canal and admittance was measured while air pressure in the ear canal was varied from +200 to –400 daPa.

Stapedius reflex thresholds were measured with headphones (TDH-39) and Interacoustics Titan IMP440 Impedance module with insert earphones at 500, 1000 and 2000 Hz, starting with contralateral reflexes. Contralateral reflexes were tested at 80 dB HL and raised until triggered or to a maximum of 110 dB HL. For ipsilateral reflexes the sound level started at 80 dB HL and was raised until triggered or to a maximum of 100 dB HL.

3.4.2. QUESTINNAIRES

In the first part of the general health-related questionnaire, the patients were asked about background characteristics (e.g. age, gender, smoking, alcohol, etc.), HA

experience, history of occupational or recreational noise exposure, tinnitus and motivation for improving their hearing and belief in their ability to use HAs. The second part of the health-related questionnaire contained questions on current work status, type of occupation, sound environment at work, etc.

3.4.3. REAL-EAR MEASUREMENTS

Before initiating the follow-up visits, training, including REM was coordinated between the lead investigators at OUH and AAUH, to ensure uniform performance of the measurements. Training in the use of the equipment and setting up the protocol was made jointly between OUH and AAUH, with the help of senior specialists from FORCE Technology, Technical-Audiological Laboratory and a senior scientist at Widex. At AAUH, all REMs were performed by the lead investigator. At OUH recruitment of student helpers was necessary towards the end of the data collection. The student helpers were thoroughly trained and it was ensured that they understood and followed protocol. After receiving practical experience with performing the REMs during the follow-up visits, the initial protocol was revised due to an ineffective work procedures. The ineffective procedure consisted of the need to turn off and remove the HA from the patient and repeating the whole of Protocol 1 (Table 3.1). In this process, the risk of displacing the probe tube and introducing a measurement error arose. Additionally, the repetition of Protocol 1 prolonged measurement time and did not take advantage of the useful measurements from the first REM. The first protocol was used from March to June 2017, after which the second protocol was used for the remainder of the project. The update in Protocol 2 resulted in only having to repeat the last three measurements in case of a HA adjustment, as the REUG and REOR/REOG and calibration was stored from the initial REM (Table 3.1)

Protocol 1 (x2 when HA-adjustments was done)	Protocol 2
REUG 65 dB (PinkNoise)	REUG 65 dB
REOG 65 dB (PinkNoise)	REOR/REOG
Calibrate for open fit	Calibrate for open fit
REIG 65 dB	REAR/REAG 55 dB
REIG 55 dB	REAR/REAG 65dB
REIG 80 dB	REAR/REAG 80 dB
	REAR/REAG 55 dB (only in case of HA-adjustments)
	REAR/REAG 65 dB (only in case of HA-adjustments)
	REAR/REAG 80 dB (only in case of HA-adjustments)

Table 3.1 Real ear measurement protocols. When nothing else is stated, the International Speech Test Signal (ISTS) was used. Protocol 1 was used in from March to June 2017 before revision of the protocol. Protocol 2 was used for the rest of the data collection. For the long form of the abbreviations please see Table 3.2.

Real ear measurements (REMs) were the first task at the follow-up visits and was performed using the REM module (REM440) of Affinity 2.0 (Interacoustics) following the REM standards: IEC 61669, (2015); ISO 12124, (2001); ANSI/ASA S3.46, (2013). The loudspeaker faced the centre of the room and the patients were positioned 1 metre away, facing the loudspeaker. Calibration of probe tubes was performed with pink noise in Protocol 1 and with the International Speech Test Signal (ISTS) (Holube *et al.*, 2010) in Protocol 2. Calibration removed the acoustic effects of the probe tube and microphone during the REM, making them 'acoustically invisible' (Pumford and Sinclair, 2001). Calibration was repeated before every REM. The calibrated probe tubes were inserted into the ear canal under visual guidance using an otoscopy to ensure that the tip of the probe tube was placed 2–5mm from the tympanic membrane. Having the probe tube closer than 2 mm can result in an adverse effect of standing waves. Correct placement of the probe tube provides accuracy within 2 dB of the true value at the eardrum up to 8 kHz, and prevents the appearance of insufficient high-frequency gain (Hawkins and Mueller, 1992).

Abbreviation	Long form	Explanation
REUG	Real Ear Unaided Gain	The input signal subtracted from the real ear unaided response.
REOG	Real Ear Occluded Gain	The difference in dB between the signal level measured in the ear canal and the input signal, with the hearing aid inserted and turned off.
REIG	Real Ear Insertion Gain	The difference between aided and unaided ear canal sound pressure level (REAR-REUR=REIG).
REOR	Real Ear Occluded Response	The sound pressure level measured in the ear canal with a hearing aid inserted and off, for a given input signal.
REAR	Real Ear Aided Response.	The output of the hearing aid (turned on) measured at the eardrum, for a particular input signal.
REAG	Real Ear Aided Gain	The gain of a hearing aid (turned on), measured at the eardrum (REAR - the input signal=REAG).

Table 3.2 Real ear measurement terminology.

The first measurement made was REUG (Table 3.2), which evaluates the natural gain provided by the pinna and the ear canal at a 65 dB SPL using a pink noise/ISTS signal (Table 3.1).

The second measurement made was the REOG/REOR. It was done using a 65 dB signal and with the HA inserted in the patients ear canal, but turned off. This is to determine the impact of the earplug on the external ear canal acoustics. The REOG is the difference in dB between the input signal and the signal measured at the tympanic membrane, whereas the REOR is the sound pressure level at the tympanic membrane for a given input signal.

In cases of an open fitted HA, the Stored Equalisation method (Hawkins and Mueller, 1992) was used in order to accommodate for the amount of sound leaking out of the ear canal and onto the reference microphone (Figure 3.2). The calibration ensures that a constant signal intensity is maintained, so as to achieve the correct measurement level at the patient's ear.

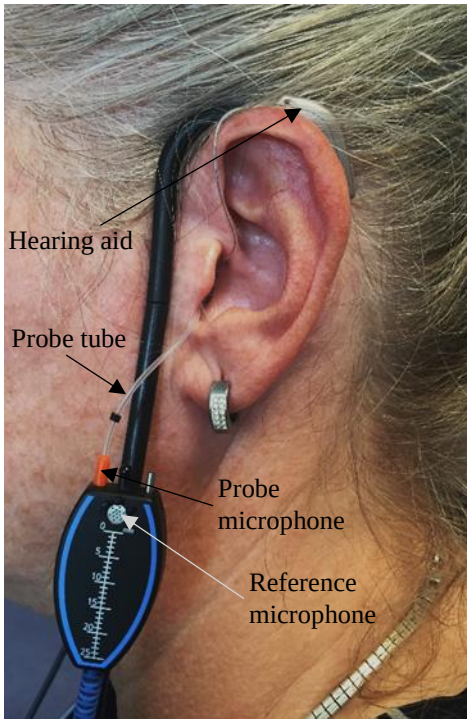

Figure 3.2 Illustration of the headset (IHM60) when mounted on a patient undergoing a real ear measurement. Hearing aid, probe tube, probe microphone and reference microphone as marked on the illustration (Photo: Wolff, A. 2018).

The third measurement, the REIG or REAR/REAG, was taken with the HA inserted and turned on. The ISTS signal was used as input at three SPLs: 55; 65; and 80 dB SPL to test the gain provided by the HA in-situ. See Table 3.2 for an explanation of the abbreviations and calculations of the different measurements.

3.5. HEARING AIDS

Danish citizens with a serviceable HL are entitled to HA treatment. Treatment in a public clinic is free of change regardless of the type of HA fitted. The HAs offered in the public clinics are regulated by a tendering procedure, which is carried out by

Amgros I/S on behalf of the five regions of Denmark. The HAs are categorised according to the type and complexity of HL. The overall categories (cat.) are cat. A/B (complex HL) and cat. C/D (less complex HL).

Due to the participation of Oticon, GN Resound and Widex in the project and to obtain balanced representation of HAs, patients were primarily fitted with HAs from one of the three manufacturers. To ensure equal distribution of HA fitted, patients were randomised to either one of the three manufactures upon entry to the study. All companies selected one of their HAs to cover the HA treatment in cat. A/B and one to cover treatment in cat. C/D. The randomisation was undertaken through REDCap according to a simple randomisation key. If HAs from the assigned company were found unsuitable, for whatever reason, an alternative was found through the tender (Table 3.3). This agreement was approved by Amgros.

Manufacture	**Number of HA fitted (%)**
Oticon	575 (29)
GN Resound	536 (27)
Widex	497 (25)
Other (Sivantos, Phonak, Rexton, Bernafon)	189 (10)
Not registered	164 (8)

Table 3.3 Distribution of HAs fitted, according to manufacturer.

Our initial objective was to register details on HA usage with regard to sound environment, program use and average usage time. The HA manufacturers' software displays different degrees of insight into the HA log data and this limited the level of detail we were able to register homogeneously across brands. Thus, the only common registration across manufacturers was the average use time of HA.

3.6. HEARING AID FITTING

The HA fitting was undertaken using a fitting strategy based on the individual HL measured with pure tone audiometry at the first visit. In the vast majority of fittings, the HAs were adjusted according to the proprietary fitting strategy developed and suggested by the HA manufacturer in question (97% of the patients completing follow-up). In some cases, fitting according to a standard fitting algorithm such as

NAL-NL1 or NAL-NL2 was done. Due to the variance of patient needs and acclimatisation effects, fitting procedures were completed by fine-tuning the HAs according to individual preferences. Acceptance of loud and high pitched noises was tested according to local tradition. In relevant cases, volume control, tele coil and streaming were activated and programs were created to fit individual needs.

3.7. DATA MANAGEMENT

The BEAR database was built using a browser-based electronic data capture system, REDCap (Harris *et al.*, 2009) hosted at OPEN, Region of Southern Denmark. The database contains basic patient information alongside their direct survey entries. An administration instrument of REDCap was used to manage the patients' appointments at the departments and distribute their survey links.

The audiological data was stored locally in AuditBase 5 (AuditData, 2018). The integration framework, NOAH System 4 (HIMSA, 2018), was used to pass results from AuditBase on to the Affinity software needed for performing the REM. After data collection, the audiological and REM data was extracted from each of the software using the CPR numbers to identify the relevant patient records. Data from the software was merged with data from REDCap and stored using SharePoint hosted by OPEN, Southern Region of Denmark.

The data analysis in the studies where performed using the statistical software STATA version 15 (Stata Corp.) and R (R Core Team, 2014).

3.8. ETHICAL CONSIDERATIONS

In accordance with Danish law, an application for ethical approval for the BEAR project (S-20162000-64) was sent to the Regional Committee on Health Research Ethics in the Region of Southern Denmark (RSD) and was not found notifiable by the committee. All studies in this thesis are part of the BEAR project, hence no further application of ethical approval was needed.

As personal data was collected and stored, notification of the BEAR project (Journal number 16/18815) was send to the Danish Data Protection Agency via the RSD in accordance with the Data Protection Act and the General Data Protection Regulation (GDPR), and was approved. All participating partners in the BEAR project signed a Data Processing Agreement containing the applicable rights and obligations when handling personal data in this project. All studies in this dissertation comply with this Data Processing Agreement made between AAUH and RSD (Journal number 18/15794). The signed agreement is filed using SharePoint at OPEN hosted by the RSD.

To ensure patients' autonomy, written, informed consent was given by the patients upon entering the project. Written information was provided by sending an information letter by email (E-Boks) to all patients before data-collection. The researchers further provided verbal information to the participants when meeting them at the clinics. Patients were made aware of their right to withdraw their consent and participation at any time without justification.

The patients were informed about confidentiality, which was obtained by the secure storage of their data. In the reporting of the data, it was ensured that individual patients could not be identified.

Patients were treated in accordance with the ethical obligation (CIOMS, 2002) to treat each patient with what is right and proper and to secure equitable distribution of the burdens and benefits of participation in the project. The only limitation and threat against this obligation is the fact that patients with cognitive impairments or who are unable to read and understand Danish were excluded from participating in the project. The exclusion criterion was based on the questionnaire restrictions. The inequitable distribution is justified as it protects the patients' rights when the patients is not capable of protecting their own interests, for example when giving informed consent.

CHAPTER 4. AIM AND HYPOTHESIS

The overall aim of the dissertation was to explore and describe health-related quality of life in patients with HL before and after treatment with HAs on the basis of the BEAR database.

The specific objectives and hypothesis of each manuscript follows.

4.1. MANUSCRIPT 1

The first manuscript's objective is to describe changes in HRQoL in new and experienced users after two months of HA treatment using their profile and total 15D score as a measure.

The first hypothesis is that experienced HA users (before HA renewal) have a lower score of HRQoL than first-time HA users (before HA fitting) at baseline. The experienced user is expected to be older and to have a more severe HL than first-time HA users.

The second hypothesis is that first-time HA users benefit more from HA treatment than experienced users after two months, when measured using 15D. This is because the first-time HA users are expected to have a smaller mean HL than the experienced users and it would therefore be easier to provide adequate alleviation.

4.2. MANUSCRIPT 2

The second paper's objective is to describe changes in outcome measures in patients with asymmetrical HL compared to patients with symmetrical HL, and to discuss the different clinical references defining asymmetrical HL.

The first hypothesis is that patients with asymmetrical HL experience lower benefits from HAs when measured with 15D and SSQ-12 before and after HA treatments compared to patients with symmetric HL.

The second hypothesis is that the type or definition of asymmetric HL is predictive of the change in outcome measures after HA treatment.

4.3. MANUSCRIPT 3

The third paper's objective is to describe the change in HRQoL when assessing HA fitting by REM measurements. The obtained real-ear aided response (REAR) is compared to a REAR-reference prescribed by the NAL-NL2.

The first hypothesis is that patients, who are fitted close to the NAL-NL2 reference obtain greater improvement in self-reported outcomes than patients fitted further from the NAL-NL2 reference.

The second hypothesis is that experienced HA users need a HA fitting closer to the NAL-NL2 reference to achieve the greatest HRQoL improvement compared to first time users.

CHAPTER 5. RESULTS AND DISCUSSION

5.1. MANUSCRIPT 1

The first manuscript of this dissertation investigates the HRQoL of first-time and experienced HA users, measured with the generic questionnaire 15D. The focus when including patients in AAUH was on first-time HA users, while the experience level of the patients was not applied as an inclusion criteria in Odense. The choice to include experienced users made it possible to investigate HRQoL in the period just before, and the benefit from, HA renewal. The general study population was stratified based on sex, severity of HL and average use time of HAs. The only group that did not significantly improve in self-reported outcome after HA treatment, as measured with the 15D, was the group of patients with severe to profound HL. This is consistent with previous findings, indicating that this group of patients have greater levels of anxiety and depression leading to a negative impact on general HRQoL (Carlsson *et al.*, 2001). With difficulty of hearing and less benefit from the use of HAs, this group of patients have a higher risk of social isolation (Hawthorne, 2008) and lower HRQoL than their better hearing peers (Hawton *et al.*, 2011). The total 15D score did not change for either of the two groups when assessed against the minimal importance change (MIC, 0.015) of the 15D. Although, when tested the group of first-time users did significantly improve in score.

The result regarding the 15D-3 showed that first-time users of HAs had higher (better) scores at baseline than did experienced HA users. When investigating the benefit after first fit/renewal of HAs, both groups showed a significantly improved 15D-3 score, although first-time users improved considerably more. The improvement found for the first-time users is consistent with the findings found by Niemensivu *et al.* (2015). The 15D-3 score was found to positively correlate with average daily use time of HAs and the patient's motivation for improving their hearing by means of HAs. The association of HRQoL and average use time of HAs has previously been reported (Laplante-Lévesque *et al.*, 2014). Likewise, the effect of motivation has been shown to have a positive impact on use time of HAs (Aazh, 2016). Additionally, improvement in sexual activity (15^{th} question of the 15D) was found to be significant in both groups. A previous study (Bakır *et al.*, 2013) found poorer sexual health in men with mild to moderate sensorineural HL. This result is supported in the study by Niemensivu *et al.*, (2015) who also makes use of the 15D-3.

5.2. MANUSCRIPT 2

The second manuscript of the dissertation investigated the impact of having AHL for the outcomes measured using 15D-3 and the SSQ12 compared to patients with SHL. In the study population only four patients had UHL, and hence, the vast majority of cases with asymmetry had bilateral HL. As no universal standard definition of AHL exists, to describe clinically relevant AHL in terms of HA treatment three different definitions were applied to the study population: interlateral difference in 1) PTA >15 dB HL, 2) WRS >15% and 3) audiogram configuration as classified by IEC 60118-15. The three definitions identified different subpopulations with AHL, with only a small common overlap (n=159). The PTA definition identified the smallest subgroup. Regardless of the definition, patients characterised as having AHL had significantly lower mean 15D-3 score than their SHL peers. After adjusting for sex, age and better hearing ear PTA (BHE-PTA), the benefit of HAs continued to be significantly lower. This is consistent with previous research (Vannson *et al.*, 2015) using the self-reported generic Glasgow Health Status Inventory (GHSI) (Gatehouse, 1999) and the SF-36 (Parving *et al.*, 2001).

The results regarding SSQ12 showed significant negative impact of AHL on the spatial domain of SSQ at baseline, for all three definitions of AHL, whereas no difference was found regarding the benefit from HA treatment between patients with AHL and their SHL peers. This suggests that although spatial hearing improves in patients with AHL after HA treatment, it does not seem to fully compensate the offset from AHL. By means of logistic regressions, BHE-PTA's contribution to the lower score in the spatial domain was assessed and was found to be an explanatory factor for the lower spatial score. No studies were found to assess the effect of SSQ12 in relation to AHL, though similar studies using UHL found that patients with UHL of similar severity of HL on the BHE as those with SHL, have compromised self-assessed speech intelligibility and increased listening efforts (Giolas and Wark, 1967; Newman *et al.*, 1997; Wie, Pripp and Tvete, 2010).

There may not be enough substantiation from drawing conclusions regarding AHL from the results of studies on UHL, though one might nonetheless speculate that the two groups experience some of the same limitations due to their asymmetry.

5.3. MANUSCRIPT 3

The third manuscript in the dissertation further investigated HRQoL in relation to REM. The study population (N=693) is patients who had REM performed according to the second protocol. The REAR was compared to a reference prescribed by the NAL-NL2 based on the individual patient audiogram. Being *on reference* was defined as a difference between REAR and REAR-reference on +/-10 dB. Data on 6 frequencies were obtained, 0.25, 0.5, 1, 2, 4 and 8 kHz. Plotting the average deviation from the NAL-NL2 reference, only nine patients were within +/- 10dB on all 6

frequencies on both ears. Restricting the number to the 4 center frequencies (0.5, 1, 2, and 4 kHz), 150 patients were within +/- 10dB on all four targets on both ears.

Comparing the score of the 15D, 15D-3, SSQ-12 and the individual SSQ domains between the patients *on reference* (*n*=150) with the patients not *on reference*, no difference were found between the groups.

The aspects of further identification of low benefit groups in terms of 15D and SSQ-12 and characterisation of their REM profiles is limited by the current study material of 693 patients, because subgroups are likely to be too small. Future analysis awaits the inclusion of additional REM data up to 1,500 cases, where the strength of statistical analyses can be substantially improved.

At time of submission the manuscript needs finishing internal review and therefore has a status of being in *preparation*.

CHAPTER 6. CONCLUSIONS AND PERSPECTIVES

The main aim of this dissertation is to investigate the group of patients referred to audiological departments for HAs and their self-reported HRQoL in relation to treatment. We hypothesised that different patient characteristics had an impact on the self-reported benefit of HA. The focus on the low-benefit groups was simply to gain knowledge of these groups in order to focus future investigations in their favour.

In the case of the experienced users' reporting an improved hearing-related quality of life after HA renewal, one could speculate whether their previous HAs were optimally fitted, which would account for the improvement after fitting optimisation. In the present work, it was not established where and when a potential decline in HL occurred prior to the renewal fitting, and whether this could have been compensated with re-fitting rather than HA renewal. Longer follow-up periods to assess the development of HRQoL over time is required. Some of the longest follow-up periods do not exceed one year.

Results from the second paper sheds new light on a group of patients who might benefit from a tailored approach to fitting, considering the specifics of the AHL. The difficulties encountered and consequences experienced regarding HRQoL when having AHL is known, but limited treatments for the offset of the asymmetry exist. In current clinical practice, if a patient is found to have an AHL upon first hearing assessment, further examinations are scheduled to rule out retrocochlear diseases. In the case of a normal follow-up examination, whether that be an auditory brainstem response (ABR) or a MRI-scanning, the conclusion is *no sign of disease*. The patient is often given the result and no further treatment or counselling is initiated. Future research is needed to explore possible ways of improving HRQoL in this group of patients. In a 2009 study (Saunders, Lewis and Forsline, 2009) which investigated the effect of prefitting counselling on HA outcomes, researchers showed a small but significant effect on matching expectations. They also found that positive expectations results in greater improved outcome. One could speculate whether advanced HA technology could be adapted to effectively compensate for the asymmetry component of AHL or perhaps additional counselling could be the option.

The results from the third manuscript showed that the HA fitting performed at the departments were very close the targets prescribed by the NAL-NL2 for the 0.25-1 kHz pure tone frequencies. The HAs were on average fitted above the reference prescribed by NAL-NL2. In contrast, the frequencies 4 and 8 kHz were showing the largest average deviation from the reference, both fitted under reference (less gain than prescribed by the NAL-NL2). Comparing the patients defined as being *on*

reference with the ones then defined as not being *on reference* showed no difference between groups when assessed on HRQoL (15D), hearing related QoL (15D-3) and hearing handicap (SSQ12). 96% of the patients were fitted with proprietary prescription which has been shown in the literature not to provide sufficient gain when compared to the prescribed gain by standard fitting algorithms (Keidser, Brew and Peck, 2003; Aarts and Caffee, 2005; Mueller, 2005). Whether REM verification of HA output should be considered a permanent part of the HA fitting procedure has not been investigated in this study. However, given the current awareness of health economics it may seem reasonable to question whether more investigation are needed before REM is considered as a part of routine.

The increase in general healthcare costs has facilitated the growing interest in objectifying the benefits gained from the money spent. In short, is the money worth the treatment? In order to make this evaluation, the need for comparison across the medical fields is needed. To this end, several generic questionnaires have been developed, but the task of creating a questionnaire sensitive to a very large number of diseases while still being feasible for patients to answer remains unsolved. The utility value associated with the QoL-questionnaires, in order to calculate QALYs, is based on answers from large evaluation surveys of the general population. This poses another potential challenge, as the general population is being asked to evaluate dimensions which they might never have experienced (Brazier *et al.*, 2018). Despite the challenges, the use of generic HRQoL questionnaires and calculations of QALYs is a valuable tool when prioritising resources. In October 2019 the Danish Medicines Council announced that the use of QALYs is being discussed for use in their further work (Poulsen, 2019). The intention for the use of QALYs is that it will provide a uniform basis for the evaluation of treatment decisions and contribute to transparency in public managements of resources according to given political strategies.

CHAPTER 7. LITERATURE LIST

Aarts, N. L. and Caffee, C. S. (2005) 'Manufacturer predicted and measured REAR values in adult hearing aid fitting: Accuracy and clinical usefulness', *International Journal of Audiology*, 44(5), pp. 293–301. doi: 10.1080/14992020500057830.

Aazh, H. (2016) *Aazh, H (2016) Feasibility of conducting a randomised controlled trial on the effect of motivational interviewing in facilitating hearing aid use*. doi: 10.17037/PUBS.02531233.

Aazh, H. and Moore, B. C. J. (2007) 'The value of routine real ear measurement of the gain of digital hearing aids', *Journal of the American Academy of Audiology*, 18(8), pp. 653–664. doi: 10.3766/jaaa.18.8.3.

Abrahamson, J. *et al.* (2005) *Seminars in Hearing. Roundtable Discussion: Outcome Measures*. Thieme Medical Publishers. doi: DOI: 10.1055/s-2005-916383.

Badia, X. *et al.* (2001) 'A comparison of United Kingdom and Spanish general population time trade-off values for EQ-5D health states', *Medical Decision Making*. SAGE Publications Inc., 21(1), pp. 7–16. doi: 10.1177/0272989X0102100102.

Bakır, S. *et al.* (2013) 'Relationship between hearing loss and sexual dysfunction', *The Journal of Laryngology & Otology*, 127(2), pp. 142–147. doi: 10.1017/S0022215112002952.

BEAR (no date) *BEAR Project*. Available at: https://bear-hearing.dk/ (Accessed: 1 December 2019).

Bengtsson, S. and Røgeskov, M. (2010) *Personer med høretab i Danmark — Socialstyrelsen - Viden til gavn*.

Bennett, K. J. and Torrance, G. W. (1996) *Measuring health state preferences and utilities: Rating scale, time trade-off, and standard gamble techniques.* 2nd edn. Edited by B. Spilker. Philadelphia: Lippincott-Raven Press.

Bentler, R. A. and Duve, M. R. (2000) 'Comparison of hearing aids over the 20th century', *Ear and Hearing*, 21(6), pp. 625–639. doi: 10.1097/00003446-200012000-00009.

Bess, F. H. (2000) 'The role of generic health-related quality of life measures in establishing audiological rehabilitation outcomes.', *Ear and hearing*, 21(4 Suppl), pp. 74S-79S. doi: 10.1097/00003446-200008001-00009.

Blandy, S. and Lutman, M. (2005) 'Hearing threshold levels and speech recognition in noise in 7-year-olds.', *International journal of audiology*, 44(8), pp. 435–43.

Boothroyd, A. (2007) 'Adult Aural Rehabilitation: What Is It and Does It Work?', *Trends in Amplification*, 11(2), pp. 63–71. doi: 10.1177/1084713807301073.

Brazier, J. *et al.* (2018) 'Experience-based utility and own health state valuation for a health state classification system: why and how to do it', *European Journal of Health Economics*. Springer Verlag, 19(6), pp. 881–891. doi: 10.1007/s10198-017-0931-5.

Carlsson, P. I. *et al.* (2001) 'Severe to profound hearing impairment: Quality of life, psychosocial consequences and audiological rehabilitation', 37(20), pp. 1849–1856. doi: 10.3109/09638288.2014.982833.

Causey, G. D. *et al.* (1983) 'A comparative evaluation of the Maryland NU 6 Auditory Test', *Journal of Speech and Hearing Disorders*, 48(1), pp. 62–69. doi: 10.1044/jshd.4801.62.

Chisolm, T. H. *et al.* (2007) 'A systematic review of health-related quality of life and hearing aids: final report of the American Academy of Audiology Task Force On the Health-Related Quality of Life Benefits of Amplification in Adults.', *Journal of the American Academy of Audiology*, 18(2), pp. 151–183. doi: 10.3766/jaaa.18.2.7.

Christensen, V. T. (2006) *Uhørt? - Betydningen af nedsat hørelse for arbejdsmarkedstilknytning og arbejdsliv*.

CIOMS (2002) 'Council for International Organizations of Medical Sciences International Ethical Guidelines for Biomedical Research Involving Human Subjects Prepared by the Council for International Organizations of Medical Sciences'. Geneva, pp. 1–58.

Cox, R. M. and Alexander, G. C. (2002) 'The International Outcome Inventory for Hearing Aids (IOI-HA): psychometric properties of the English version: El Inventario International de Resultados para Auxiliares Auditivos (IOI-HA): propiedades psicometricas de la version en ingles', *International Journal of Audiology*. Taylor & Francis, 41(1), pp. 30–35. doi: 10.3109/14992020209101309.

Cox, R. M., Alexander, G. C. and Beyer, C. M. (2003) 'Norms for the international outcome inventory for hearing aids.', *Journal of the American Academy of Audiology*, 14(8), pp. 403–13.

Cox, R. M., Johnson, J. A. and Xu, J. (2014) 'Impact of advanced hearing aid technology on speech understanding for older listeners with mild to moderate, adult-onset, sensorineural hearing loss.', *Gerontology*, 60(6), pp. 557–68. doi:

10.1159/000362547.

Dalton, D. S. *et al.* (2003) 'The Impact of Hearing Loss on Quality of Life in Older Adults', *Gerontologist*. Oxford University Press, 43(5), pp. 661–668. doi: 10.1093/geront/43.5.661.

Dawes, P. *et al.* (2015) 'Hearing loss and cognition: The role of hearing aids, social isolation and depression', *PLoS ONE*. Edited by B. Johnson. Public Library of Science, 10(3), p. e0119616. doi: 10.1371/journal.pone.0119616.

Douglas, S. A. *et al.* (2007) 'Spatial hearing disability after acoustic neuroma removal', *Laryngoscope*, 117(9), pp. 1648–1651. doi: 10.1097/MLG.0b013e3180caa162.

Drummond, M. F. *et al.* (2015) *Methods for the Economic Evaluation of Health Care Programmes - Michael F. Drummond.pdf*. 4th edn. Oxford University Press.

Dumper, J. *et al.* (2009) 'Indications for bone-anchored hearing AIDS: a functional outcomes study.', *Journal of otolaryngology - head & neck surgery = Le Journal d'oto-rhino-laryngologie et de chirurgie cervico-faciale*, 38(1), pp. 96–105.

Dwyer, N. Y., Firszt, J. B. and Reeder, R. M. (2014) 'Effects of unilateral input and mode of hearing in the better ear: Self-reported performance using the speech, spatial and qualities of hearing scale', *Ear and Hearing*, 35(1), pp. 126–136. doi: 10.1097/AUD.0b013e3182a3648b.

Elberling, C., Ludvigsen, C. and Lyregaard, P. E. (1989) 'Dantale: A new danish speech material', *Scandinavian Audiology*. doi: 10.3109/01050398909070742.

EuroQoL Group (1990) 'EuroQol - a new facility for the measurement of health-related quality of life', *Health Policy*. Elsevier, 16(3), pp. 199–208. doi: 10.1016/0168-8510(90)90421-9.

Fellinger, J. *et al.* (2005) 'Mental distress and quality of life in a deaf population', *Social Psychiatry and Psychiatric Epidemiology*. Steinkopff-Verlag, 40(9), pp. 737–742. doi: 10.1007/s00127-005-0936-8.

Ferrans, C. E. *et al.* (2005) 'Conceptual model of health-related quality of life', *Journal of Nursing Scholarship*, pp. 336–342. doi: 10.1111/j.1547-5069.2005.00058.x.

Firszt, J. B., Reeder, R. M. and Holden, L. K. (2017) 'Unilateral Hearing Loss: Understanding Speech Recognition and Localization Variability-Implications for Cochlear Implant Candidacy.', *Ear and hearing*. NIH Public Access, 38(2), pp. 159–

173. doi: 10.1097/AUD.0000000000000380.

Francis, H. W. *et al.* (2002) 'Impact of Cochlear Implants on the Functional Health Status of Older Adults', *The Laryngoscope*, 112(8), pp. 1482–1488. doi: 10.1097/00005537-200208000-00028.

Franck, B. A. M. *et al.* (1999) 'Evaluation of spectral enhancement in hearing aids, combined with phonemic compression', *The Journal of the Acoustical Society of America*, 106(3), pp. 1452–1464. doi: 10.1121/1.428055.

Gatehouse, S. (1999) *Glasgow Hearing Aid Benefit Profile : Derivation and Validation of a Client-centered Outcome Measure for Hearing Aid Services*, *J Am Acad Audiol*.

Gates, G. A. and Mills, J. H. (2005) 'Presbycusis', *The Lancet*. Elsevier, 366(9491), pp. 1111–1120. doi: 10.1016/S0140-6736(05)67423-5.

Giolas, T. G. and Wark, D. J. (1967) 'Communication Problems Associated with Unilateral Hearing Loss', *Journal of Speech and Hearing Disorders*, 32(4), pp. 336–343. doi: 10.1044/jshd.3204.336.

Harford, E. and Barry, J. (1965) 'A Rehabilitative Approach to the Problem of Unilateral Hearing Impairment: The Contralateral Routing of Signals (CROS)', *Journal of Speech and Hearing Disorders*, 30(2), pp. 121–138. doi: 10.1044/jshd.3002.121.

Harris, P. A. *et al.* (2009) 'Research electronic data capture (REDCap)-A metadata-driven methodology and workflow process for providing translational research informatics support', *Journal of Biomedical Informatics*, 42(2), pp. 377–381. doi: 10.1016/j.jbi.2008.08.010.

Hartley, D. *et al.* (2010) 'Use of hearing aids and assistive listening devices in an older australian population', *Journal of the American Academy of Audiology*, 21(10), pp. 642–653. doi: 10.3766/jaaa.21.10.4.

Häusler, R., Colburn, S. and Marr, E. (1983) 'Sound localization in subjects with impaired hearing: Spatial-discrimination and interaural-discrimination tests', *Acta Oto-Laryngologica*. Informa Healthcare, 96(S400), pp. 1–62. doi: 10.3109/00016488309105590.

Hawkins, D. and Mueller, H. (1992) 'Procedural considerations in probe-microphone measurements.', in Mueller, H., Hawkins, D., and Northern, J. (eds) *Probe Microphone Measurements.* San Diego: Singular Publishing, pp. 67–90.

Hawthorne, G. (2008) ‘Perceived social isolation in a community sample: Its prevalence and correlates with aspects of peoples’ lives’, *Social Psychiatry and Psychiatric Epidemiology*, 43(2), pp. 140–150. doi: 10.1007/s00127-007-0279-8.

Hawton, A. *et al.* (2011) ‘The impact of social isolation on the health status and health-related quality of life of older people’, *Quality of Life Research*, 20(1), pp. 57–67. doi: 10.1007/s11136-010-9717-2.

Hickson, L., Clutterbuck, S. and Khan, A. (2010) ‘Factors associated with hearing aid fitting outcomes on the IOI-HA’, *International Journal of Audiology*, 49(8), pp. 586–595. doi: 10.3109/14992021003777259.

Holube, I. *et al.* (2010) ‘Development and analysis of an International Speech Test Signal (ISTS)’, *International Journal of Audiology*. Taylor & Francis, 49(12), pp. 891–903. doi: 10.3109/14992027.2010.506889.

Horsman, J. *et al.* (2003) ‘The Health Utilities Index (HUI®): Concepts, measurement properties and applications’, *Health and Quality of Life Outcomes*. doi: 10.1186/1477-7525-1-54.

Hougaard, S. and Ruf, S. (2011) *EuroTrak I: A Consumer Survey About Hearing Aids in Germany, France, and the UK - Hearing Review, Hearing Review*. Available at: http://www.hearingreview.com/2011/02/eurotrak-i-a-consumer-survey-about-hearing-aids-in-germany-france-and-the-uk/ (Accessed: 22 October 2019).

Humphriss, R. L. *et al.* (2004) ‘Change in hearing handicap after translabyrinthine vestibular schwannoma excision.’, *Otology & neurotology : official publication of the American Otological Society, American Neurotology Society [and] European Academy of Otology and Neurotology*, 25(3), pp. 371–8. doi: 10.1097/00129492-200405000-00028.

Ishine, M., Okumiya, K. and Matsubayashi, K. (2007) ‘A close association between hearing impairment and activities of daily living, depression, and quality of life in community-dwelling older people in Japan [8]’, *Journal of the American Geriatrics Society*. John Wiley & Sons, Ltd (10.1111), pp. 316–317. doi: 10.1111/j.1532-5415.2007.01067.x.

Joore, M. A. *et al.* (2002) ‘Response shift in the measurement of quality of life in hearing impaired adults after hearing aid fitting’, *Quality of Life Research*. Kluwer Academic Publishers, 11(4), pp. 299–307. doi: 10.1023/A:1015598807510.

Jorgensen, L. E. (2016) ‘Verification and validation of hearing aids: Opportunity not an obstacle.’, *Journal of otology*. Chinese PLA General Hospital, 11(2), pp. 57–62. doi: 10.1016/j.joto.2016.05.001.

Kaplan-Neeman, R. *et al.* (2012) 'Hearing aid satisfaction and use in the advanced digital era', *The Laryngoscope*, 122(9), pp. 2029–2036. doi: 10.1002/lary.23404.

Keidser, G. *et al.* (2011) 'The NAL-NL2 prescription procedure', *Audiology Research*, 1(1S). doi: 10.4081/audiores.2011.e24.

Keidser, G., Brew, C. and Peck, A. (2003) 'Proprietary fitting algorithms compared with one another and with generic formulas', *Hearing Journal*, 56(3), pp. 28–38. doi: 10.1097/01.HJ.0000293014.56004.ee.

Laplante-Lévesque, A. *et al.* (2014) 'Patterns of Hearing Aid Usage Predict Hearing Aid Use Amount (Data Logged and Self-Reported) and Overreport', *Journal of the American Academy of Audiology*, 25(2), pp. 187–198. doi: 10.3766/jaaa.25.2.7.

Lutman, M. E., Brown, E. J. and Coles, R. R. (1987) 'Self-reported disability and handicap in the population in relation to pure-tone threshold, age, sex and type of hearing loss.', *British journal of audiology*, 21(1), pp. 45–58.

Mueller, H. G. (2005) *Fitting Hearing Aids to Adults Using Prescriptive Methods: An Evidence-Based Review of Effectiveness, J Am Acad Audiol*.

Mulrow, C. D. *et al.* (1990) 'Quality-of-life changes and hearing impairment. A randomized trial.', *Annals of Internal Medicine*. American College of Physicians, 113(3), pp. 188–94. doi: 10.7326/0003-4819-113-3-188.

Newman, C. W. *et al.* (1990) 'The hearing handicap inventory for adults: Psychometric adequacy and audiometric correlates', *Ear and Hearing*, 11(6), pp. 430–433. doi: 10.1097/00003446-199012000-00004.

Newman, C. W. *et al.* (1997) 'Perceived hearing handicap of patients with unilateral or mild hearing loss.', *Annals of Otology, Rhinology and Laryngology*. Annals Publishing Company, 106(3), pp. 210–214. doi: 10.1177/000348949710600305.

Niemensivu, R. *et al.* (2015) 'Health-related quality of life in adults with hearing impairment before and after hearing-aid rehabilitation in Finland.', *International journal of audiology*, 54(12), pp. 967–75. doi: 10.3109/14992027.2015.1077400.

Nilsson, M., Soli, S. D. and Sullivan, J. A. (1994) 'Development of the Hearing In Noise Test for the measurement of speech reception thresholds in quiet and in noise', *Journal of the Acoustical Society of America*, 95(2), pp. 1085–1099. doi: 10.1121/1.408469.

Noble, W. *et al.* (2013) 'A short form of the Speech, Spatial and Qualities of Hearing scale suitable for clinical use: The SSQ12', *International Journal of Audiology*, 52(6),

pp. 409–412. doi: 10.3109/14992027.2013.781278.

Noble, W. and Gatehouse, S. (2004) ‘Interaural asymmetry of hearing loss, Speech, Spatial and Qualities of Hearing Scale (SSQ) disabilities, and handicap.’, *International journal of audiology*, 43(2), pp. 100–14.

OECD and European Union (2018) *OECD/EU (2018), Health at a Glance: Europe 2018: State of Health in the EU Cycle, OECD Publishing, Paris. https://doi.org/10.1787/health_glance_eur-2018-en*. OECD (Health at a Glance: Europe). doi: 10.1787/health_glance_eur-2018-en.

Olsen, S. Ø. O., Hernvig, L. H. and Nielsen, L. H. (2012) ‘Self-reported hearing performance among subjects with unilateral sensorineural hearing loss’, *Audiological Medicine*, 10(2), pp. 83–92. doi: 10.3109/1651386X.2012.673755.

Parving, A. *et al.* (2001) ‘Some Experiences with hearing disability/Handicap and quality of life measures’, *International Journal of Audiology*, 40(4), pp. 208–214. doi: 10.3109/00206090109073116.

Parving, A. (2011) *Hvert femte høreapparat ender i skuffen | Hørelse.info*. Available at: https://hoerelse.info/hvert-femte-horeapparat-ender-i-skuffen (Accessed: 22 October 2019).

Peissig, J. and Kollmeier, B. (1997) ‘Directivity of binaural noise reduction in spatial multiple noise-source arrangements for normal and impaired listeners’, *The Journal of the Acoustical Society of America*. Acoustical Society of America, 101(3), pp. 1660–1670. doi: 10.1121/1.418150.

Perez, E. and Edmonds, B. A. (2012) ‘A systematic review of studies measuring and reporting hearing aid usage in older adults since 1999: A descriptive summary of measurement tools’, *PLoS ONE*. doi: 10.1371/journal.pone.0031831.

Poulsen, A. G. (2019) ‘Ny i Medicinerrådet: Hils på QALY’, *Danish medical journal*, 21.

Pumford, J. and Sinclair, S. (2001) ‘Real Ear Measurement: Basic Terminology and Procedures’, *Phonak*, (C), pp. 1–13.

Ricketts, T. A. and Galster, J. (2008) ‘Head angle and elevation in classroom environments: Implications for amplification’, *Journal of Speech, Language, and Hearing Research*, 51(2), pp. 516–525. doi: 10.1044/1092-4388(2008/037).

Saunders, G. H., Lewis, M. S. and Forsline, A. (2009) ‘Expectations, prefitting counseling, and hearing aid outcome’, *Journal of the American Academy of*

Audiology, 20(5), pp. 320–334. doi: 10.3766/jaaa.20.5.6.

Scoggins, J. F. and Patrick, D. L. (2009) 'The use of patient-reported outcomes instruments in registered clinical trials: evidence from ClinicalTrials.gov.', *Contemporary clinical trials*. NIH Public Access, 30(4), pp. 289–92. doi: 10.1016/j.cct.2009.02.005.

Scollie, S. *et al.* (2005) 'The Desired Sensation Level Multistage Input/Output Algorithm', *Trends in Amplification*, 9(4), pp. 159–197. doi: 10.1177/108471380500900403.

Shield, B. (2019) 'Evaluation of the social and economic costs of hearing impairment. A report for Hear-it', p. 250.

Singh, G. and Pichora-Fuller, K. M. (2010) 'Older adults' performance on the speech, spatial, and qualities of hearing scale (SSQ): Test-retest reliability and a comparison of interview and self-administration methods', *International Journal of Audiology*, 49(10), pp. 733–740. doi: 10.3109/14992027.2010.491097.

Sorri, M. *et al.* (2001) 'Will hearing healthcare be affordable in the new millennium', *Scandinavian Audiology*, 30(3), pp. 203–204. doi: 10.1080/010503901316914584.

Stark, P. and Hickson, L. (2004) 'Outcomes of hearing aid fitting for older people with hearing impairment and their significant others', *International Journal of Audiology*, 43(7), pp. 390–398. doi: 10.1080/14992020400050050.

Summerfield, A. Q. and Barton, G. R. (2019) 'Sensitivity of EQ-5D-3L, HUI2, HUI3, and SF-6D to changes in speech reception and tinnitus associated with cochlear implantation', *Quality of Life Research*. Springer International Publishing, 28(5), pp. 1145–1154. doi: 10.1007/s11136-018-2070-6.

Swan, I. R. C., Guy, F. H. and Akeroyd, M. A. (2012) 'Health-related quality of life before and after management in adults referred to otolaryngology: a prospective national study.', *Clinical otolaryngology : official journal of ENT-UK ; official journal of Netherlands Society for Oto-Rhino-Laryngology & Cervico-Facial Surgery*, 37(1), pp. 35–43. doi: 10.1111/j.1749-4486.2011.02433.x.

Vannson, N. *et al.* (2015) 'Quality of life and auditory performance in adults with asymmetric hearing loss.', *Audiology & neuro-otology*. Karger Publishers, 20 Suppl 1(Suppl. 1), pp. 38–43. doi: 10.1159/000380746.

Vermiglio, A. J. *et al.* (2012) 'The Relationship between High-Frequency Pure-Tone Hearing Loss, Hearing in Noise Test (HINT) Thresholds, and the Articulation Index', *Journal of the American Academy of Audiology*, 23(10), pp. 779–788. doi:

10.3766/jaaa.23.10.4.

Ware, J. E. and Sherbourne, C. D. (1992) 'The MOS 36-item short-form health survey (Sf-36): I. conceptual framework and item selection', *Medical Care*, 30(6), pp. 473–483. doi: 10.1097/00005650-199206000-00002.

WHO (2017) 'Facts about deafness', *WHO*. World Health Organization. doi: 10.1016/j.amjmed.2013.04.026.

Wie, O. B., Pripp, A. H. and Tvete, O. (2010) 'Unilateral deafness in adults: effects on communication and social interaction.', *The Annals of otology, rhinology, and laryngology*, 119(11), pp. 772–81.

William Yund, E. and Buckles, K. M. (1995) 'Multichannel compression hearing aids: Effect of number of channels on speech discrimination in noisea)', *Journal of the Acoustical Society of America*, 97(2), pp. 1206–1223. doi: 10.1121/1.413093.

Wittrup-Jensen, K. and Pedersen, K. (2008) 'Modelling Danish Weights for the 15D Quality of Life Questionnaire by Applying Multi-Attribute Utility Theory (MAUT)', *Health EconomicsPapers 2008:7*, (2), pp. 1–35.

Wyatt, J. R. *et al.* (1996) 'Cost Utility of the Multichannel Cochlear Implant in 258 Profoundly Deaf Individuals', *The Laryngoscope*, 106(7), pp. 816–821. doi: 10.1097/00005537-199607000-00006.

ISSN (online): 2246-1302
ISBN (online): 978-87-7210-553-6

AALBORG UNIVERSITY PRESS