Sound localization and Quality of Life after Cochlear implantation in patients with Single-Sided Deafness

Master Thesis

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by
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Declaration

I declare that I have developed and written the enclosed Master Thesis completely by myself, and have not used sources or means without declaration in the text. Any thoughts from others or literal quotations are clearly marked. This work was not used in the same or in a similar version to achieve an academic grading or is being published elsewhere.

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Abstract

In the present Master Thesis, the aspects of sound localization and the Quality of Life (QoL) in Single Sided Deafness (SSD) after Cochlear implantation (CI) have been investigated. SSD is defined as a condition where an individual has non-functional hearing in one ear and the contralateral ear presents with normal audiometric function. No clinical benefit from amplification in the non-functional ear can be received and the resulting asymmetric hearing loss includes reduced abilities to localize sound in the horizontal plane [1]. It is generally recognized that sound source localization in SSD is one of the major issues to overcome and therefore rehabilitation with the treatment of a Cochlear Implant (CI) may improve sound source localization.

The ORL-Departement, University Hospital St. Pölten, Austria, routinely administers CI's in patients with indicated hearing loss. Ten SSD-CI patients were recruted to evaluate the outcome of CI treatment in SSD. The investigated subjects received a CI from MED-EL (Medical Electronics, Innsbruck, Austria) and were tested with the Sonnet Audio Processor (AP).

The study group (n=10) comprised eight female and two males with a mean age of 48 years (ranging from 19 – 72 years). The mean PTA4 in the normal hearing ear (PTA4-NH) was 11,25dB and the mean PTA4 in the deaf ear (PTA4-SSD) was 93,88dB. The main outcome measures for the SSD-CI study cohort was (1) speech understanding in noise, using the Oldenburger Sentence Test (OLSA) with Sound (S) and Noise (N) from the front (S0N0), and (2) sound localization. (3) Patients' satisisfaction was evaluated by two different hearing related questionnaires: the Abbreviated Profile of Hearing Aid Benefit (APHAB) and the short form of the Speech, Spatial, and Qualities of Hearing Scale (SSQ12). These instruments appear to be sensitive to the impact of device use and may indicate whether improvements on laboratory-based tests generalize to everyday listening situations.

Data analysis was done using SPSS (version 22). Statistically significance was established for p-values < 0,05. The Student t-test was used in the statistical comparison.

The comparison of the means resulted in significant improvement in (1) the OLSA sentence test in noise (S0N0), (2) the sound localization evaluation as well as the administred (3) questionnaires, the APHAB and the SSQ12.

Kurzfassung

Die vorliegende Masterarbeit behandelt das Thema des Richtungshörens und der Patientenzufriedenheit mittels Fragebögen nach einer Cochlea Implantation, bei Patienten mit vorbestehender einseitiger Taubheit. Bei einseitiger Taubheit ist es nur schwer bis kaum möglich die Richtung einer Schallquelle auszumachen, daher ist eine empfohlene Behandlungsmethode, Patienten mittels eines Cochlea Implantates zu versorgen um Probleme beim Richtungshören zu verbessern.

An der HNO-Abteilung des Universitätsklinikums St. Pölten, werden routinemäßig Patienten mit Cochlea Implantaten versorgt. Um die Ergebnisse bei einseitiger Taubheit nach Cochlea Implantation zu evaluieren, wurden zehn Patienten die mit einem MED-EL Implantat System und dem Sonnet Audio Prozessor (Medical Electronics, Innsbruck, Österreich) versorgt wurden, untersucht.

Inkludiert wurden acht Frauen und zwei Männer mit einem Durchschnittsalter von 48 Jahren (von 19 – 72 Jahren). Der mittlere Reinton gemessen über vier Frequenzen (PTA4) im normal hörenden Ohr (NH) betrug 11,25dB und der PTA4 auf dem tauben Ohr (PTA4-SSD) betrug 93,88dB. Das Sprachverstehen der Patienten im Störlärm wurde mittels des Oldenbruger Satz Testes (OLSA) mit Geräusch (S) - als auch dem Störgeräusch (N) von vorne (S0N0) getestet. Weiters wurde eine Richtungshör-Prüfung mit und ohne eingeschaltetem Sprachprozessor durchgeführt. Um die Patientenzufriedenheit zu messen wurden zwei standartisierte, hörspezifische Fragebögen verwendet: „Abgekürztes Bewertungsprofil für Hörhilfen“ (APHAB) und die Kurzform des Fragebogens „Sprache, räumliches Hören und Hörqualität“ (SSQ12).

Die Ergebnisse wurden im Statistikprogramm SPSS (Version 22) analysiert um nachzuweisen ob in den unterschiedlichen Kategorien eine signifikante Verbesserung mittels t-test erzielt werden konnte (signifikant $p<0,05$).

Der Vergleich der unterschiedlichen Mittelwerte zeigte, dass sowohl im Sprachtest, dem OLSA (S0N0), als auch im Richtungshören, sowie bei den beiden verwendeten Fragebögen, die Verbesserung nach Cochlea Implantation signifikant war ($p<0,05$).

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1 Outlook

1.1 Structure of the Thesis

The first chapter describes the motivation and the research questions of this master thesis. The following chapter is dealing with the topic hearing loss, the rehabilitation with an implantable hearing aid, the Cochlear Implant and the changes of indication criteria for an implantation especially in case of Single Sided Deafness. The third chapter deals with the literature review of the actual studies to the topic of sound localization in Single Sided Deafness. The fourth chapter describes our own done study and its design to this topic, to answer the pivotal questions. The last chapter contains the discussion and the conclusion.

1.2 Motivation

The aim of this master thesis was to evaluate the possible benefits of Cochlear Implants (CI) in patients with Single Sided Deafness (SSD).

In the US, the incidence of bilateral hearing loss among people greater than 12 years old is 12.7% and this number is estimated to increase to 20.3% after including unilateral hearing loss, also known as Single Sided Deafness [2]. In other words, 1 out of 8 in the population had bilateral hearing loss and 1 in 5 had either a bilateral- or an unilateral hearing loss [3].

Unilateral deafness, also known as Single Sided Deafness often has its onset in adulthood and is often sudden and idiopathic [4].

Single Sided Deafness can occur in the adult population as a result of, or in conjunction with sudden sensorineural hearing loss (SSNHL), acoustic neuroma removal and Meniere’s disease. Considering the incidence of these disorders together, it is estimated that 10.4 to 25.4/100 000 are at risk for SSD [5].

A recognizable audiological handicap may already be presented by a small asymmetry between the ears, especially in challenging noisy situations [4]. Thus, all degrees of hearing impairment in one ear already depicit substantial listening difficulties in everyday situations. SSD impairs the ability to understand speech in noise and to localize sounds and also limits awareness of sounds that are located on the side of the hearing impaired ear [6].

One approach to improve the awareness of sounds on the side of the hearing impaired ear is to reroute signals to the contralateral, normal hearing ear. This contralateral routing of signals (CROS) was first achieved by connecting a hearing aid microphone on the side of the deaf ear to a hearing aid on the normal hearing ear [7], [4]. Contralateral routing of signal hearing aids however, are poorly accepted. The acceptance rate of conventional CROS devices has been reported to be as low as 10 - 20% due to the occlusion of the better hearing ear and insufficient benefit [8].

Since 2002 Bone Anchored Hearing Aids (Baha) are approved for the treatment of SSD which were originally developed for conductive or mixed losses [9], [4]. Another alternative to treat patients with SSD would be bone conduction implants (BCI), such as the BONEBRIDGE (MED-EL, Medical Electronics, Innsbruck, Austria). In studies comparing the CROS hearing aid to the BAHA and BCI, out of a total of 72 patients 63 (87.5%) preferred to receive a BCI [5].

Initially, Cochlear implantation was performed for suppressing tinnitus, but it has recently been considered for the treatment of SSD aiming the restoration of binaural hearing [10], [4]. Recent technical progress established CI as an effective treatment in SSD to improve speech comprehension and sound localization [11], [12], [13]. CI implantation for SSD has been established in Austria since 2011 [14]. Since then the technology of implantable hearing devices is constantly developing, with Audio Processors (APs) presenting more and mulitple features such as noise reduction and adaptive microphones, despite evermore decreasing dimensions of Implants as well as APs. To evaluate the present standards of Implants and Audio Processors, studies reporting on SSD and sound localization were reviewed and summarized and compared to our own clincially evalutated CI-SSD patients.

1.3 Challenges

CI in SSD is a realtively “new” treatment that facilitates the patients everyday life, and scientific evidence is still sparse. Especially in relevant Journals only a few studies discuss the topic of CI as an effective treatment in SSD. The few studies available primarily examined changes in self-reported difficulties with listening and behavioral measures of speech perception before and after providing patients with a device. Due to the differences in the study design and outcomes of those studies no recommendation could be given [4]. Furthermore, most studies soley raised the question of improvement of sound localization and only a few dealt with patient-reported outcome instruments. As a consequence, the here presented study aims to correlate the individual listening and behavioral measures via localization- and speech testings in noise in the aided and un-aided condition, with patient satisfaction measures evaluated via two most commonly used instruments, the APHAB and the SSQ. These instruments appear to be sensitive to the impact of device use and may indicate whether improvements on laboratory-based tests generalize to everyday listening situations [4].

1.4 Pivotal Research Questions

- Can patients who suffer unilateral deafness and were treated with a Cochlear Implant localize sound better?
- Does such an intervention improve the patients' quality of life?

1.5 Objectives

To answer these questions, a literature review of present studies on the topic of sound localization after Cochlear implantation was performed, followed by the empiric evaluation of a SSD-CI study cohort. The study subjects underwent sound localization testing, speech understanding tests in noise and answered two health related quality of life questionnaires comparing the unaided with the CI-aided condition.

2 Theoretical Background

This chapter contains basic information about the utilized CI (Synchrony, MED-EL, Medical Electronics, Innsbruck, Austria): device description, device indications and the therewith associated preoperative audiological testing, and the rehabilitation after Cochlear implantation. Furthermore, it describes the changes of indication criteria for the implantation of a CI, the topic of sound localization in normal hearing and in case of unilateral hearing loss.

2.1 Cochlear Implant

Cochlear Implants are indicated for patients with severe to profound sensorineural hearing loss. In such cases the hair cells of the cochlea are partial or fully damaged. Hair cells detect movement at their specific places on the membrane, which the brain interprets as sound with a certain frequency and intensity. Another essential property of hair cells is phase-locking. Hair cells release neurotransmitters only at a specific phase of the sonic waveform. This synchronization of vibrations in the air, in the basilar membrane and in the activity of neurons in the resonant region is called phase-locking, an important response mechanism in the auditory system. The information gained with phase-locking is critical for sound localization, music and pitch perception, and speech understanding in noise. In the auditory system, the response of hair cells in the basilar membrane is phase-locked to low frequency sound waves. Damage to these hair cells results in significantly decreased hearing sensitivity with almost no ability to understand speech or localize sounds, if left untreated or only treated with conventional hearing devices [15]. Furthermore, those inner ear hair cells cannot regenerate, this damage is permanent and up to date no medical treatment is available.

The first attempt of a CI was performed in 1957 in Paris, placing a wire on the auditory nerve of a patient who was just by chance undergoing surgery. The wire was used to stimulate the auditory nerve directly with electrical current and the person reported a clear auditory percept. The first single channel CI was introduced in 1972. Over 1000 people were implanted from 1972 to the mid 1980s including several hundred children [16].

This early stage of a single channel device was well tolerated but provided the users with limited ability of hearing at the different frequencies and understanding of words compared to the latest generation devices. The CI since then has been constantly improved and further developed to a multichannel transcutaneous implant [14]. Today, different CI systems are available and comprise electrode arrays with multiple contacts that are inserted into the scala tympani of the cochlea via an opening (cochleostomy) that is surgically created just lateral to the round window. The number of contacts (or electrodes) and the way in which those contacts can be configured varies across devices but they all are multi-channel rather than single-channel devices.

2.1.1 Device description

The MED-EL Cochlear Implant system consists of two parts: The external part the Audio Processor and the internal part the Implant which is implanted under the skin. The CI system takes up the function of the affected inner ear. The microphone of the Audio Processor detects sound and converts it into electric impulses which are transmitted to the magnetic coil of the processor. This coil sends these impulses by induction through the skin to the receiver of the Implant. At the implant the signals are decoded and sent to the electrode array which is implanted into the cochlea. If signals with low frequencies are detected, electric impulses are sent to the apical part of the electrode and for signals containing high frequencies electric impulses are sent to the basal part. This system mimics normal hearing, in which the same conditions and places of the cochlea frequencies are detected and sent to the auditory nerve [14].

Figure 1 below shows a CI from the Austrian hearing implant company MED-EL with the two different parts: the external part, the Audio Processor and the internal part, the Implant.

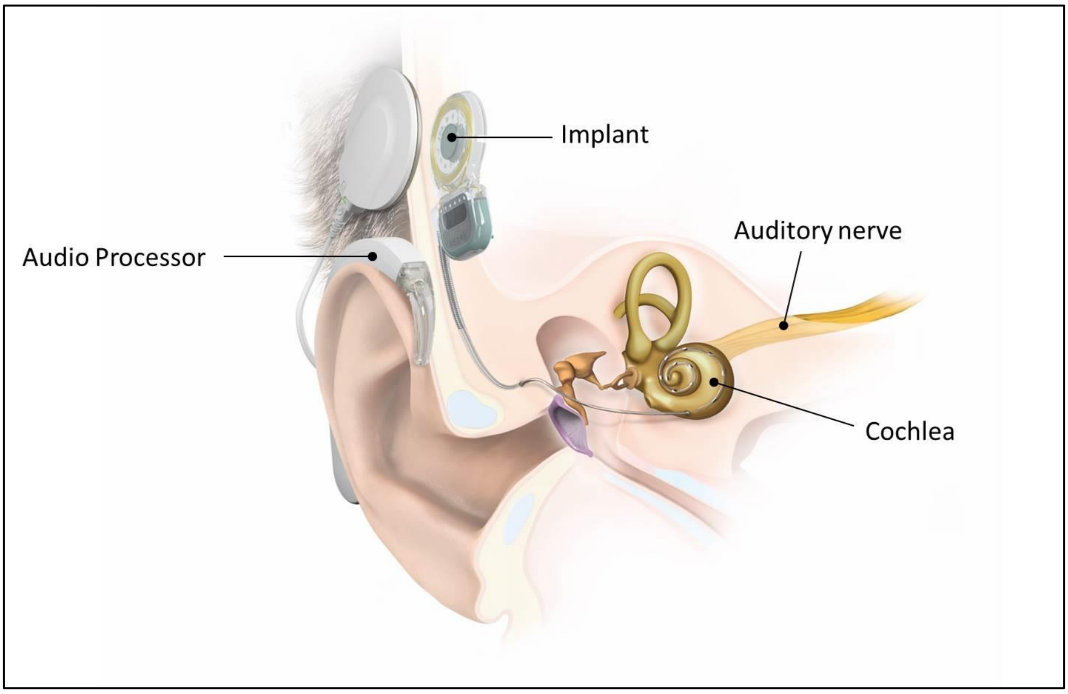

Figure 1 MED-EL Cochlear Implant “Synchrony” with the Audio Processor “Sonnet” showing a multichannel Electrode inserted into the Cochlear

2.2 Indications for Cochlear Implant

Generally, Cochlear Implants are an option for all patients who are likely to hear and understand speech better with an implant than with a hearing aid. Candidates for CI are children, adolescents and adults who lost their hearing after speech acquisition, as well as children who fully or partly lost their hearing before or during speech acquisition. In exceptional cases, adults who went deaf before acquiring speech are implanted if it is medically and audiologically indicated. There is essentially no age limit for implantation. Children are generally implanted from six months of age after decisive diagnosis has been achieved. If both ears are affected, the child will be implanted on both sides. Adults also receive an implant in each ear if medically and audiologically indicated. To determine the candidacy for a Cochlear implantation several factors need to be clarified: A candidate's hearing is checked by various tests. Standard audiological procedures are pure tone and speech audiometry, testing and optimising the candidate's hearing aid (including audiometric procedures in sound field), objective measures and impedance audiometry are included. Radiological procedures such as CT and MRI scans are performed to check whether the auditory nerve and auditory pathways are working. In children, paediatric audiologists assess the child's hearing as well as their speech and language development and communication skills. For adults, clinics usually use the following values: a person qualifies as a candidate from an audiological standpoint, if they only hear unaided acoustic signals from 70dB. This roughly equates to the volume of a running car engine at a distance of 10 metres. Testing frequencies are from 250Hz to 8,000Hz. Additionally, candidates must perform a series of comprehensive and multi-disciplinary pre-operative diagnostic tests [12].

The audiological testing's for adults split up in subjective- and objective tests. At subjective audiological tests, the cooperation of the patient is necessary. At objective audiological tests the cooperation of the patient is not necessary.

Subjective measurements include:

- pure-tone audiometry
    - air conduction and bone conduction
- speech audiometry (via headphones and/or loudspeaker)
    - with and without conventional hearing aids

During the pure tone audiometry (PTA) test, signals at different decibels (dB) over headphones are presented and the patient should signalize as soon the signal is heard. First tests are performed in air conduction (AC), followed by bone conduction (BC), using a special bone conduction headphone measuring the hearing level (HL) for each ear. Based on the measured HL the patients' degree of hearing loss can be deciphered [15].

At the speech audiometry monosyllables are presented over headphones. The patient is asked to repeat the words understood. Goal is to find out, at which level of loudness the patient is able to understand 100% of the presented words correct, beginning at 65 dB in 15 dB steps up to 110dB over headphones. This measured outcome gives the speech understanding for each ear. If the patient is aided with conventional hearing aids, the speech understanding with the hearing aids has to be tested as well. Monosyllables are presented via loudspeakers and the patient is asked to repeat the words understood. If a patient is bilaterally aided, the words have to be tested in three conditions: – (1) separate for each ear, and (2) with both conventional hearing aids, to evaluate the benefit or in such cases the limited benefit [15].

Objective measurements include:

- tympanometry
- stapedius reflex measurement
- brainstem evoked response audiometry (BERA)

Tympanometry is an examination used to test the condition of the middle ear and mobility of the eardrum (tympanic membrane) and the conduction bones by creating variations of air pressure in the ear canal. After visual inspection of the ear canal and eardrum a probe is inserted in the ear canal with a flexible rubber tip to seal the ear canal enabling the measurement of changes in air pressure. A probe tone is sent to the eardrum and if the atmospheric pressure in front and behind the ear is nearly the same the transmission of the probe tone is the best. The second part of this measurement is to measure the difference of pressure of the eardrum to identify if there is a problem in the middle ear, behind the eardrum [15]. The presence of fluid behind the eardrum is the most common cause of an abnormal tympanogram. Fluid in the middle ear space prevents the eardrum from moving and transmitting sound properly, and this condition is nearly always temporary and medically treatable. If you there is fluid in the ear, it may not be necessary to correct the hearing loss with a hearing implant.

The acoustic reflex (stapedius reflex, attenuation reflex, or auditory reflex) is an involuntary muscle contraction that occurs in the middle ear in response to high-intensity sound stimuli or when the person starts to vocalize as a sort of safety control system. The contraction of the stapedius muscle stiffens the middle-ear, thus decreasing middle-ear admittance, which can also be measured via tympanometry: A suddenly appearing loud probe tone is sent to the middle ear and the automatic contraction of the musculus stapedius can be detected. Due to this contraction, the tension of the eardrum raises and sounds can be reduced in its loudness. If a patient has severe hearing loss the stapedius reflex cannot be triggered and detected [15].

The BERA is a test to measure the brain wave activity that occurs in response to clicks or certain tones. It is an objective measurement to evaluate the hearing loss without the cooperation of the patient. Electrodes are placed on the scalp, on both sides of the mastoid, another electrode is placed at the vertex (highest point of the scalp) and a ground electrode is placed on the zygomatic bone. For this measurement, acoustic signals are presented via headphones or plug in headphones. The electrodes pick up the brain's responses to these sounds and record them. [15].

2.3 Expansion of Indication Criteria

Since the first Cochlear implantation a lot of research has been directed to further improve electronic implantable devices. Since the first implantation of a CI in the early 1980 up til know the indication criteria for implanation has expanded. Furthermore the number of implants with different electrodes which vary in length and flexibility has increased, offering more options for patients and enabling better performance in speech understanding [17]. Also the surgery itself is becoming minimal invasive with an average surgery time of less then an hour for experienced surgeons.

2.3.1 Cochlear Implants in Adults

The first patients which were treated with a CI had to be post linguallly deaf on both ears with zero percent of speech understanding at the maximum tolerated loudness. During the last years, the indication criteria for adults have changed enormous. In 1990, adult patients were also indicated with residual hearing but zero percent in speech understanding. Since 1998 also the minimum percent speech understanding has changed to a score of under 40 percent in quiet at the maximum tolerated loudness level. Today, the indication criteria have changed to severe to profound sensorineural hearing loss and a speech understanding in quiet under 50 percent, enabling patients earlier access to implantation and possibly easier rehabilitation [18].

2.3.2 Cochlear Implants in Children

In the early days, only adult patients were indicated for a CI. In 1990, the indication criteria were extended that also prelingual and postlingual children 2 years of age or older with residual hearing could be implanted. This age limit decreased in 1998 to a minimum age of 18 months. Today the minimum age for children receiving a CI is set to twelve months of age [18].

2.3.3 Cochlear Implants in Single Sided Deafness

In 2011, the indication criteria for CI were extended to treat Single Sided Deafness. The years before only conventional hearing aids like CROS-hearing aids were possible. All treatment methods, with the exception of the CI, never rehabilitate the deaf ear. The unilateral electric stimulation with a CI can rehabilitate the deaf ear [17] instead of just trying to compensate with a conventional hearing aid the disabilities of sound localization and speech understanding in difficult environments.

2.4 Sound Localization

Sound localization is the ability to determine the location of a sound and where it originates from directionally. The auditory systems use different cues for auditory localization such as differences between what the left and the right ear perceives. Therefore, to localize sounds, humans need two ears, both with normal hearing or with at least symmetric hearing loss. Where a sound comes from depends on two different criteria in the horizontal plane: The intensity of the sound and the time difference sound reaches the facing and the far side ear, named the interaural level differences (ILD) and the interaural time differences (ITD) respectively. Humans can localize sounds if the signal suddenly changes, this means that for example a constant signal like wind cannot be localized well, by the sense of hearing.

The time delay of signals depends on where the sound comes from. If a sound reaches the right ear first and the left second, the sound source will be localized on the right side. The bigger the time difference between the right and the left ear the further the sound source is on the right side. If the sound is detected at the same time on both ears which means there is no time delay, the signal could originate from the front or from behind. Humans are able to detect sound delays between 10 and 30 µs, which corresponds to a detection difference of 3°.

Also, the intensity of sound can be analysed. This depends on the size of the sound waves; the head works as a sound shadow for sounds with higher frequencies above 3000 Hertz. At lower frequencies, the sound wave is too big that the head is a barrier for the signal [19].

A different hearing threshold level between both ears, especially Single Sided Deafness, causes problems in localization of sound. In such cases the time and intensity difference of sound cannot be perceived. It is well known, that patients with Single Sided Deafness cannot localize for example from which side a car comes from. In cases with mild to severe unilateral hearing loss, a rehabilitation with a conventional hearing aid is neccesary and may be sufficient to localize sounds again. In cases with Single Sided Deafness, the gold standard method to localize sound again is to rehabilitate with a CI.

2.5 Rehabilitation after Cochlear Implantation

One of the most important topics in CI is the rehabilitation after the surgery. Hearing with a CI is not the same as normal hearing. The electric stimulation of the different areas of the cochlea differs from acoustic hearing. In the cochlea, the sound vibrations vibrate the basilar membrane. The basilar membrane contains thousands of hair cells that move in response to the pressure from sound waves sending out electrical pulses. Different hair cells respond to different frequencies of sound, and they are positioned from bottom of the membrane responding to high-frequency sounds up to the top, responding to low-frequency sounds. A CI is designed to replicate the electrical pulses that the hair cells create. Once the electrode array is inserted into the cochlea, it is close enough to the nerve cells that it can send them electrical signals. That’s why there are multiple contacts in an electrode array: different contacts are located along the cochlea to provide electrical pulses to the areas that replicate a wide range of sound frequencies. When an electrical pulse is sent from the electrode array, it stimulates a targeted region of the auditory nerve’s nerve cells. These nerve cells then relay a natural electrical nerve signal on to their neighbour, and so on down the line until they reach the auditory cortex. So, once these electrical signals reach the nerve cells of the auditory nerve, they are treated exactly like they would be if they were created by the cochlea’s hair cells [14]. Therefore, it is very important to adjust the calibration called map of the CI perfectly to mimic normal hearing. To ensure this, cooperation of the patient is necessary to adjust the most comfortable level in loudness (MCL) for each channel of the CI. A given electric impulse is perceived as loudness. The patient responses if the MCL is reached, or if the impulse is too little or too much. The MCL-Level is adjusted exactly to the patients' needs. In the first month, the MCL-level can change due to the change of the individual perception.

To optimize the performance and individual patients' satisfaction the ENT-Department of the University Hospital St. Pölten, created a schedule for the rehabilitation after Cochlear implantation:

1. Two weeks after surgery the first- also called initial fitting takes places. At this appointment, the patients receive their own speech processors. This first fitting also includes an implant check-up, were the impedances of the electrodes and the specification of the MCL-Level of the different electrodes according to the patients' needs is measured. Additionally, the patient receives a technical introduction on how to handle the speech processor and the accessories.

2. One week after the first fitting (approximately 3 weeks after surgery) the second control takes place. This appointment is used to clarify possible open questions regarding the CI system. Furthermore, another check-up of the implant and an optimization of the MCL-Levels are performed.

3. Three weeks after the one week fitting (approximately 6 weeks after surgery) the one month control takes place. At this session, the first hearing performance will be evaluated, measuring the hearing level aided with the CI. Following another implant-check, and MCL-level optimization procedure.

4. Three months after the three-week fitting (approximately 18 weeks after surgery) in addition to the implant check-up and the fitting, the first speech understanding of numbers is being tested. If the patients' outcome for speech understanding of numbers is satisfying, a monosyllables speech test would be applied.

5. At the Six months' evaluation (approximately 6 1/2 months after surgery) another implant check-up is performed. Followed by a MCL-Level optimization fitting. The following audiological tests are performed: Evaluation of the hearing level with the CI and speech understanding

tests with numbers and monosyllables with varying intensity levels. In the here presented SSD-CI study cohort an additional speech understanding in noise test is performed.

6. The next evaluations are scheduled one and two years after surgery and the same evaluations as for the six months' appointment are performed. If problems or additional questions arise, additional appointments can be made.

2.6 Auditory Training after Cochlear Implantation

To optimize the patients' individual performance in speech understanding an auditory training is recommended. Since the CI sends auditory information to the brain, sometimes the brain needs help to re-learn how to process this information. Especially if someone has had a long-term hearing loss, even if they used hearing aids, this means their brain might have gone decades without hearing some sounds. To remember hearing and understand speech are two different components. On the one hand, patients with CI can hear sounds very soon after the first fitting or even at the date of activation. On the other hand, the auditory system needs time to convert the signals in speech and to understand them [14].

Therapy material for the auditory training after Cochlear implantation is available and the following scheme of the program "Richtig Üben, Richtig Verstehen", gives a short overview of the training steps. Each part is based on the previous exercise and should be exercised in this order:

- Exercises on the understanding of numbers
- Exercises on the understanding of names
- Exercises for the understanding of names for cities and places
- Exercises for colour understanding
- Exercises to discriminate tone pitches
- Exercises to discriminate intonation
- Exercises for telephone in every day's life
- Exercises with phrases
- Theme-based exercises with words and sentences
- Exercises on speech comprehension at the word and sentence level
- Exercises of sentences with personal nouns/modal verbs [20].

- Exercises on sentence comprehension (open set)
- Exercises with similarly sounding syllables/words/sentences
- Exercises with words and sentences of certain initials
- Exercises with prefixes and suffixes
- Exercises on the understanding of the text [21].

For an auditory training a training-partner, who auditions similar exercises, is necessary. The program is based on a printed version of all exercises. Additionally, audio files are available to enable training alone, without a training-partner. The exercises comprise several response possibilities, were the patient is asked to tick the answer understood. At the end of each category the given answers are compared to correct ones [20], [21].

In bilateral hearing loss, the exercises can be performed easily by presenting the audio files via a loudspeaker. In Single Sided Deafness, this setting is not useful as the normal hearing ear would compensate speech understanding in quiet. Therefore, a set-up for the CI implanted side only is necessary using direct stimulation of the CI witch auditory accessories like a FM-cable or a neck loop. Both variants bypass the normal hearing ear and solely exercise the CI implanted side. For using the FM-cable a cable, a connection of the Audio Processor with an external sound source is necessary. The wireless possibilities of the neck loop allow the same stimulation.

3 Literature Review

The following chapter summarizes popular studies dealing with the topic of Single Sided Deafness after Cochlear implantation. The main outcomes reported are sound localization and speech understanding with different treatment options.

3.1 Arndt et al.

The paper by Arndt et al. is one of the first studies on CI in SSD, a German study from Freiburg all following mentioned studies refer to this study. The Authors describe in their study: "Einseitige Taubheit und Cochleaimplantat-Versorgung", the results of eleven SSD-CI patients and the different measurement methods applied [27]. Most of the eleven patients had a sudden hearing loss resulting in a profound to severe hearing loss on one side. Furthermore, the indication criteria for SSD was a hearing loss on the better ear less than 30dB at the frequencies between 0,5kHz to 3kHz. This comprensive study tested sound localization, speech understanding in noise and the patient satisfaction with different questionnaires. The sound localization test set-up comprised nine loudspeakers in a frontal horizontal semicircle, one meter at the patients' head level, 30 degrees to each other. The sound localization testings were carried out under different conditions. From each speaker came ten signals in five different loudness level. For the signal, they used sentences form the "Oldenburger Satztest" (OLSA). The OLSA sentence comprises of five words: a name, verb, numeral, adjective and an object. The sentences are meaningless to avoid complementation by the patient. For example "Doris malt neun nasse Sessel" [28]. The patients were tested in four different conditions: with CROS-hearing aid, a BAHA headband (not implanted), SSD untreated and SSD-CI. Speech understanding using the OLSA was tested 65 dB noise, with varying loudness of the sentences depending on the patients' answers [27]. The more correct words are identified, the more the presentation level of the next sentence is reduced until a fixed level is reached. If words are incorrect or not understood the volume of the next sentence will increase again. The goal is to find out at which volume (dB) the patient has 50 percent of the words correct [28]. Three loudspeakers were used: one in front of the patient at zero degrees and two at 45 degrees left and right from the centre speaker. The patients performed six measurements, with three different arrangements, comparing noise and sentences in the untreated SSD and SSD-CI condition. First, the signal and the sentences came from the front. Second, sentences were presentedf from the deaf ear side and noise from the normal hearing side and third, sentences were presented from the normal hearing side and noise from the deaf ear side. The best results in sound localization were found in the SSD-CI group. No differences in sound localization were found comparing SSD, CROS-hearing aid and BAHA. Speech understanding in noise showed no significant difference when both signals come from the front of the patient, or the sentences come from the normal hearing side and the noise from the deaf side between SSD and SSD-CI. A significant improvement in speech understanding in noise in the SSD-CI group was detected when sound was coming from the deaf ear side and the noise from the normal hearing side. The administred questionnaires also resulted in significant improvement in patients' quality of life [27].

3.2 Zeitler et al.

Zeitler et al. describes in the study: "Sound Source Localization and Speech Understanding in Complex Listening Environments by Single-sided Deaf Listeners After Cochlear Implantation" the results of nine SSD-CI patients [22]. To compare the results in sound localization and speech understanding, 45 younger normal hearing listeners (NH), twelve older NH listeners and 27 bilateral CI (BCI) patients were tested. The age range in the group of NH ranged from 21 to 40 years and reported pure-tone thresholds were 20 dB or less between the frequencies 125 Hertz (Hz) up to 4 kilo Hertz (kHz). The age range in the older NH group was from 51 to 70 years with pure-tone thresholds of 20dB or less measured between 125Hz to 2kHz and at 3kHz not more than 30dB. The BCI patients age range was from 32 to 70 years and the SSD-CI patients from 12 to 63 years.

The SSD inclusion criteria was a pure-tone average four (PTA4, 500 Hz, 1kHz, 2kHz, 4kHz) of 20dB or less in the normal hearing ear.

For the localization test a wideband noise was presented from one of 13 loudspeakers arranged in a semicircle. The patient was positioned in the center of the loudspeaker setup and was asked to call the number of the loudspeaker the signal was coming from.

To test the speech understanding in noise the patient was seated in the center of eight loudspeakers which were arranged in a circle. Restaurant noise was recorded and presented from all loudspeakers at the same time. Sentences were presented from the nearest loudspeaker to the deaf ear, one turn was with the CI and one without presenting the sentences from the same direction.

The results show that all CI patients, independent whether they were bilateral-CI or SSD-CI showed poorer outcome than the NH control groups for both ages. Three of the nine SSD-CI patients were as good as the best bilateral-CI patients. This study also shows a significant improvement of speech understanding in noisy environment aided with CI.

Unforutnaltey this study does not compare sound localization in SSD-CI with CI aided and CI unaided patients [22].

3.3 Nawaz et al.

Nawaz et al. describes in their case report: “Improving Sound Localization After Cochlear Implantation and Auditory Training for the Management of Single Sided Deafness” the medical history and audiological results of one SSD patient [23]. In this case report a 49-year-old man suffered sudden hearing loss in the left ear. The right ear was normal hearing with a PTA4 of 20dB or less. The patient works as a road engineer and has to localize fast vehicles on the roads for his own safety. He complains that after experinceing the sudden hearing loss he was not able to localize cars anymore. He was wearing a CROS-hearing aid without improvement in sound localization. A few years later a bone-anchored-hearing aid (BAHA) was implanted, at the left side [23]. This treatment option also does not offer hearing on the deaf ear. A BAHA in SSD detects the signals on the deaf side and directed via bone conduction through the skull to the normal hearing inner ear [24]. The patients’ signal detection improved but not the sound localization. The audiologists tested sound localization with a setting of 20 loudspeakers. The patient had to look at the centre loudspeaker at zero degrees in front of him. From one of the other 19 loudspeaker a pink noise was presented for a short time and the patient had to detect the correct loudspeaker the signal was coming from. Each loudspeaker was activated twice in a randomised setting. This setup was tested with and without the BAHA. The results showed that most sounds without the BAHA were localized on the normal hearing side. With the BAHA switched on, the results improved slightly, but there was no consistency in the responses. The results were not as good as expected and he, therfore decided to opt for another device, the CI. The BAHA was explanted and he received a CI instead. Four weeks after the implantation the CI was activated. The patient underwent a few fittings of the CI and the audio processor to optimize the performance, followed by some sound localization testings under the same conditions as with the BAHA tested before. The results in case of SSD-CI showed much closer respnoses to normal hearing [23].

3.4 Dorman et al.

The study: “Interaural Level Difference Cues Determine Sound Source Localization by Single Sided Deaf Patients Fit with a Cochlear Implant” by Dorman et al. [25] describes the benefit of sound localization in a target group of four SSD-CI patients in relation to a group of normal hearing and CI patients with conventional hearing aids on the contralateral side. The inclusion criteria for normal hearing, was characterized due to the pure tone average of 20dB or less in the frequencies 125Hz up to 4kHz. The authors used three different signals to test for differences in localization. Signal one was a wideband noise (WB), signal two a wideband noise with a low pass filter (LP) and the third signal was a wideband noise with a high pass filter (HP). The stimuli were presented from eleven of thirteen loudspeakers in a semicircle, were the speakers at the beginning and at the end of the arrangement were not used. The results showed that the SSD-CI patients can localize sound better with CI activated than with CI off, but also report better outcomes compared to CI patients with conventional hearing aids. The results of the different signals also indicated, that the localization answers in WB and HP were compareable and almost the same, wheras the LP signal was worse compared to the other two signals [25].

3.5 Mertens et al.

Another study found from Mertens et al. named: ”Prospective case-controlled sound localization study after Cochlear implantation in adults with Single Sided Deafness and ipsilateral tinnitus” include ten SSD patients which were tested for sound localization [26]. The inclusion criteria for SSD patients was a PTA3 (0,5 kHz, 1kHz and 2kHz) of 25dB or less at the normal hearing ear. One of the ten patients however was out of criteria as he presented with a PTA3 of 32dB, meaning no normal hearing on the contralateral side. The authors tested five left- and five right-sided SSD-CI patients. The sound localization test set-up included nine loudspeakers in a frontal horizontal semicircle at the patients’ head level. Three different stimuli were applied: a broadband noise (BB), a low-pass noise

(LP) and a high-pass noise (HP). Patients were tested with all three stimuli with CI on and CI off. The control group, comprised normative data of 30 normal hearing subjects (no further details regarding inclusion or exclusion criteria given). The patients had to answer the number of the speaker they thought the stimuli came from. The signal was presented three times from each speaker in a randomized way. The patients repeated the testing six times for every signal with CI on and CI off to compare the results. The results showed that the patiens were able to localize sound for all the three different signals with CI on better than with CI off. The SSD-right group had a localization tendence to the right side with CI off and vice versa for the SSD-left patients [26].

4 Empirical Study (SSD-CI)

Since 2000, the University Hospital in St. Pölten, Austria routinely implants CI's. With the expansion of indication criteria, described in chapter 2.3, patients with unilateral hearing loss, especially SSD patients are now able to also benefit from a CI operation. To evaluate the possible improvement in auditory performance and Quality of Life, a study with SSD patients receiving a CI was performed. Based on the afore mentioned international studies a study protocol was created to complement the experienced research lacks/gaps and implement further improvements to the presented study setups.

4.1 Study Design

The study comprised a monocentric prospective, intra-subject measurements design. Each subject served as his/her own control and was additionally compared to normative levels of normal hearing subjects. The setting is University Hospital St. Pölten, Austria.

4.2 Material and Methods

4.2.1 Patients

Ten patients diagnosed with SSD were tested for speech understanding in noise, sound localization, and Quality of Life via questionnaires.

Patients included in the study should present with a stable profound to severe sensorineural hearing loss of one year or more in one ear. The normal hearing side is characterised with PTA4 (mean of the frequencies, 0,5kHz, 1kHz, 2kHz and 4kHz) of 20dB or less. The minimum age is 18 years.

All ten patients were implanted with a Med-El Cochlear Implant (MED-EL Medical Electronics, Innsbruck, Austria). The experiences with the CI had to be at least six months or more at the date of measurement.

The control group for the sound localization test comprised of ten normal hearing subjects, older than 18 years with a PTA4 (mean of the frequencies, 0,5kHz, 1kHz, 2kHz and 4kHz) of 20dB or less for both ears.

Table 1 summarizes the ten subjects included, of which eight were female and two were male. Six were implanted on the left side and four on the right side. The mean age of the study cohort was 48 years, ranging from 19 to 72 years. The mean age at implantation was 45,6 years rainging from 18 to 68 years. Seven cases reported sudden HL. One subjects' Single Sided Deafness afflicted from an accident causing trauma to the head. One subject suffered from congenital HL since childhood and in one case reported progressing hearing loss over time. The mean PTA4 in the Normal Hearing ear (NH) was 11,25dB and the mean PTA4 in the deaf ear (SSD) was at 93,88dB.

Table 1 Patients demographics

Patient ID	Implanted side	sex	age	age at surgery	cause of HL	Pure Tone Average (PTA4)	
						NH	SSD
P_01	R	f	65	63	sudden HL	11,25	120
P_02	L	f	59	57	sudden HL	10	111,25
P_03	R	f	19	18	progredient HL	3,75	78,75
P_04	R	f	53	48	sudden HL	17,5	90
P_05	L	f	52	51	sudden HL	12,5	65
P_06	L	m	51	50	sudden HL	7,5	112,5
P_07	R	f	21	18	since childhood	8,75	77,5
P_08	L	f	72	68	sudden HL	18,75	72,5
P_09	L	f	63	62	sudden HL	11,25	91,25
P_10	L	m	25	21	fracture	11,25	120
Mean:			48	45,6		11,25	93,88

4.3 Audiometry

The ten study participants (SSD-CI) were tested with the new “Sonnet” AP with the microphone mode set to ‘natural’. Before starting the audiological tests, the implant was checked up and a fine tuning of the map of the CI was done to the patients needs.

4.3.1 Speech understanding in noise

To measure the benefit of speech understanding in noise the adaptive OLSA was conducted [28]. Sentences (S) and noise (N) were presented from a loudspeaker in front of the patients head with a distance of one meter. Both signals (S and N) start at 65dB, sentences were adapted based on the answers of the patient, whereas the noise stayed constant (S0N0).

Twenty sentences were measured in the unaided as well as CI-aided condition. A test run of ten sentences was carried out, to help the patient feel confident with the situation.

Speech understanding in noise results were compared against each other: unaided condition (SSD), CI aided (SSD-CI) vs. the normal hearing results.

4.3.2 Sound localization test

For the sound localization test, seven loudspeakers were placed in a frontal horizontal semicircle, with a distance to the patients’ head of one meter (please see schematic presentation of the sound localization setup in the Figure 2 below).

The direction from the speaker signal was randomized with one full set of measurement containing 42 items.

Three different sound levels and two different noises were presented. The three levels were 65dB, 70dB and 75dB to reduce the bias of the interaural level differences (ILD) because in a SSD condition, sounds which were presented on the the affected ear seems to be not as loud as the same sound on the normal hearing ear.

To reduce the bias of the interaural time differences (ITD) a spectrally shaped Comité Consultatif International Téléphonique et Télégraphique (CCITT) noise was generated. By using the ipsilateral and contralateral side, the head related transfer functions were used for filtering a noise from a virtual stimulus at 90°

(right ear side). These two outcomes are from now on referred to as signal 1 and signal 2, respectively.

Each stimulus was pesented once: for all seven speakers, with both signals (1 and 2) and at the tree different soundlevels (65dB, 70dB and 75dB).

During the presentation of the signals the patients were asked to look at the loudspeaker in front of them. The speakers were numbered from left to right, and the patient had to identify the number of the speaker were signals were presented from. Patients were prompted to answer spontaneously and only once, leaving no room for speculation or consideration.

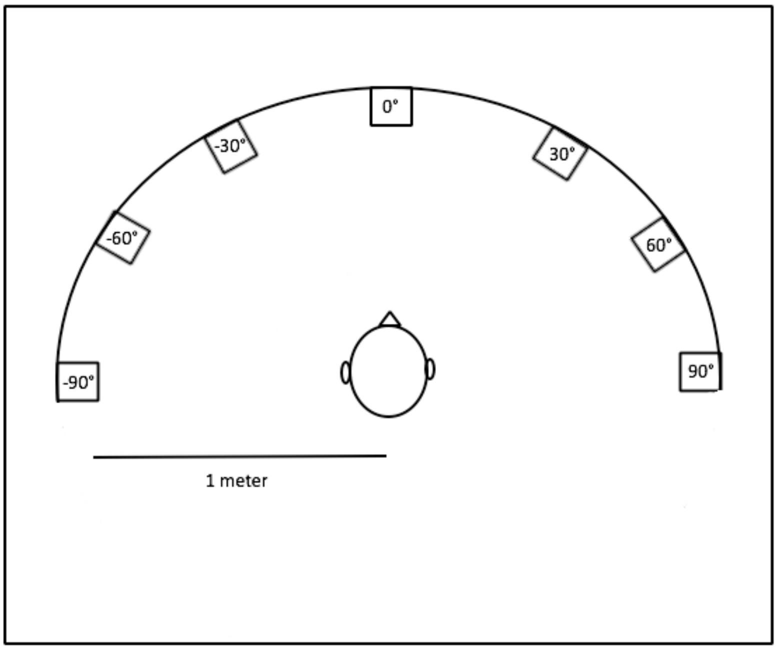

Figure 2 Schematic setup of the sound localization test, showing the semicirular setup with 7 loudspeakers

The sound localization software was written in Matlab with and output of results into Excel. The following Table 2 shows a short few of the saved results of the sound localization test. At the first column, the item nuber is saved. At the scecond column, the kind of signal- the sound source, at the third column, the loudness of the three different level in dB, at fourth column, the loudspeaker at which the signal was presented and at the last column, the answer which the patient had given, is saved.

Table 2 Output of the sound localization test from Matlab.

Item Nr.	Sound source	Loudness in dB	Item in degree	Answer in degree
1	2	70	30	-90
2	1	70	90	-60
3	2	75	0	30
4	2	75	-90	-90
5	1	60	60	90

To demonstrate the individual failure a Root Mean Score Error (RMSE) and the bias was calculated. This is a frequently used meausure to differentiate between vaues predicted by a model and the values actually observed. In this case the RMSE describes the mean deviation between the answer and presentation speaker in degree. RMS Error is derived by squaring the differences between known and unknown points, dividing that by the number of test points, and at the end taking the square root of that result. The bigger the RMSE the bigger the difference between presentation items and the individual answers [29].

The bias describes the shift of the answers to the axis of symmetry, which means to the axis of zero degree. The bias is derived by the differences between the known and the unknown points and dividing by the number of testpoints. A negative bias represents a shift of the answers to the left ear and a positive bias represents a shift of the answers to the right ear [29].

4.4 Subjective Benefit (Quality of Life)

To evaluate the patients' Quality of Life two questionnaires were administred. In general quality of life can be characterised by the standard of health, comfort, and happiness experienced by an individual or group. It observes life satisfaction, including everything from physical health, family, education, employment, wealth, religious beliefs, finance and the environment. Two disearse-specific questionnares were chosen, namey the Abbreviated Profile of Hearing Aid Benefit questionnaire (APHAB) and the Speech, Spatial and Qualities of Hearing Scale (SSQ). Each questionnaire was administred twice, once before CI implantation (untreated) and once after CI implanation (SSD-CI treated), to evaluate the subjective benefit, measured as the difference between pre- and post implantation.

4.4.1 Abbreviated Profile of Hearing Aid Benefit questionnaire (APHAB)

The APHAB contains 24 questions related to everyday situations in difficult sound environments. Patients are asked questions regarding their troubles in having communications in different day to day situations. Seven possible answers, listed from A to G are given. "A" corresponds to "every time" and returns a percentage of 99 percent, wheras "G" corresponds to "never" and returns the percentage of one percent. The questionnaire is structured into four subscales: Ease of Communication (EC), Reverberation (RV), Background Noise (BN), and Aversiveness (AV) [30].

The subscale EC contains questions of situations about speech understanding in small groups or quiet environments. RV reflects the issue of speech understanding in different challenging noise/reverberant conditions. BN includes questions regarding speech understanding in the presence of multitalker bubble or in group conversations, where more than one person speaks at the same time. The subscale AV contains items to noisy conditions, environmental sounds, uncomfortable for the patient, such as the sound of a smoke detector.

4.4.2 Speech, Spatial and Qualities of Hearing Scale (SSQ)

The original questionnaire contains 49 questions in three different subscales to the topics of speech understanding in difficult conditions (speech hearing items, abbreviated- SH), for example a conversation in a restaurant with background noise, sound localization (spatial hearing items, also called localization hearing-LH) or the quality of sounds (quality of hearing items QH) [31]. Noble et al.

compared the original SSQ49 with the SSQ12 and results showed comparable resutls between the tests [32]. Therfore, the short form of this questionnaire the SSQ12 was used. The test contains enough information to evaluate the different aspects of hearing and the test is short enough to ensure compliance of the patients.

The scoring scheme is a simple analogue ruler/numeric rating scalewere the left-hand end represents complete disability and the right-hand end complete ability. The higher the SSQ scores, the greater the ability [33]. A zero means for example that speech in a group of people cannot be understood at all, and a ten means that the understanding is perfect. If the statement is not relevant for the patient, it could be ticked up the possibility “does not apply”. The results of the answers SSD and SSD-CI have been compared and analysed. Both questionnares, the APHAB and the SSQ12 were administered twice: first in the SSD untreated condition and second after implantation in the SSD-CI condition.

5 Results

The following chapter summarizes the results of the speech understanding in noise test investigated via the OLSA in the two conditions of SSD (untreated) and SSD-CI (treated). The two health related QoL questionnaires, the APHAB and the SSQ12 were administered before and after intervention, and improvenment was calculated. The sound localization test was analyzed for each patient and vizualized for the conditions SSD and SSD-CI to see the individual differences in the mean of the answers. Also the RMSE and the bias were calculated. In addition the patients were separated in two groups, the SSD-CI left and SSD-CI right side, to decipher possible differences in the outcomes.

5.1 Audiometry

5.1.1 Speech Understanding in Noise

To evaluate the speech understanding in noise the OLSA sentence test was used. Figure 3 describes the results of the testing. All ten patients were first tested in the untreated condition (SSD) followed by the CI-treated condition (SSD-CI), both times the sentences (S) and the noise (N) came from the same loudspeaker in front of the patient (S0N0). The vertical axis of the graph represents the level of loudness in dB and on the horizontal axis shows the two different conditions (SSD vs. SSD-CI). The results indicate that the loudness level of the sentences is less than the level of the background noise resulting in a negative signal to noise ratio (-SNR). In the SSD condition a mean of -3,35 dB SNR and in the SSD-CI condition a mean of -5,29 dB SNR was measured. The reference value for bilateral normal hearing in the same condition S0N0 is reported with a mean of -7dB SNR (± 1,1dB). To convert the dB SNR in %, the difference of each dB has to be multiplied with 17 [15]. Which means that 1dB difference is an improvement of 17% in speech understanding in noise [15].

The difference of speech understanding in noise with the CI is 1,95dB SNR which is an enhancement of 32,98%.

To evaluate the difference in speech understanding in noise, the mean results of the two different conditions SSD and SSD-CI were analysed in SPSS. The t-test for two individual means of the OLSA for speech understanding revealed significant difference p<0,05 (see Apendix A).

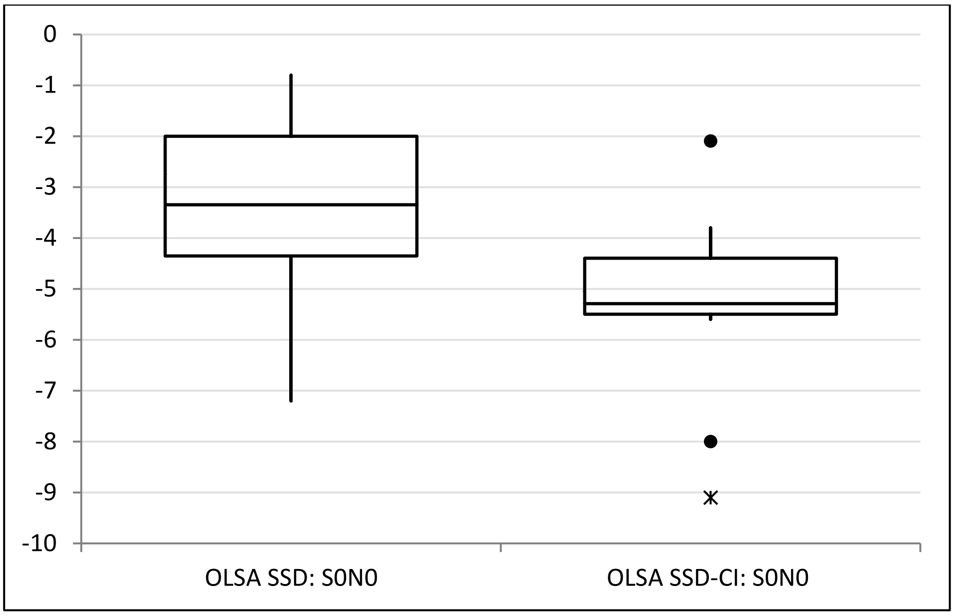

Figure 3 Box-plot presenting the results of the OLSA speech understanding in noise measurements (SNR).

5.1.2 Sound Localization

The results of the sound localization test were plotted in a four quadrant coordinate system. The area above the horizontal line is characterised as the right side of the patient, quarter 1 and 2. The 2 quadrants below the horizontal line represent the left side of the patient, quarter 3 and 4. The transversal line is subdivided into seven marks from -90° to 90°, representing the seven loudspeakers. If the presented 42 items are answered correctly the outcomes would fit these seven marks on the transveral line. Results shown in corner 2 indicate outcomes of signals which were presented on the right side of the patient, from the right hand loudspeaker and answered/identified correctly. If signals are presented on the right side of the patient but are heard/identified on the left side the answers will be marked in corner 3. The more left, right signals were located the more down the horizontal line in corner 3 they were marked. Left side presented signals and correct located were presented in corner 4. If they were heard on the right-side answers were marked in corner 1.

Figure 4 illustrate the explanations to the coordinate system of the visualization of the results of the sound localization test.

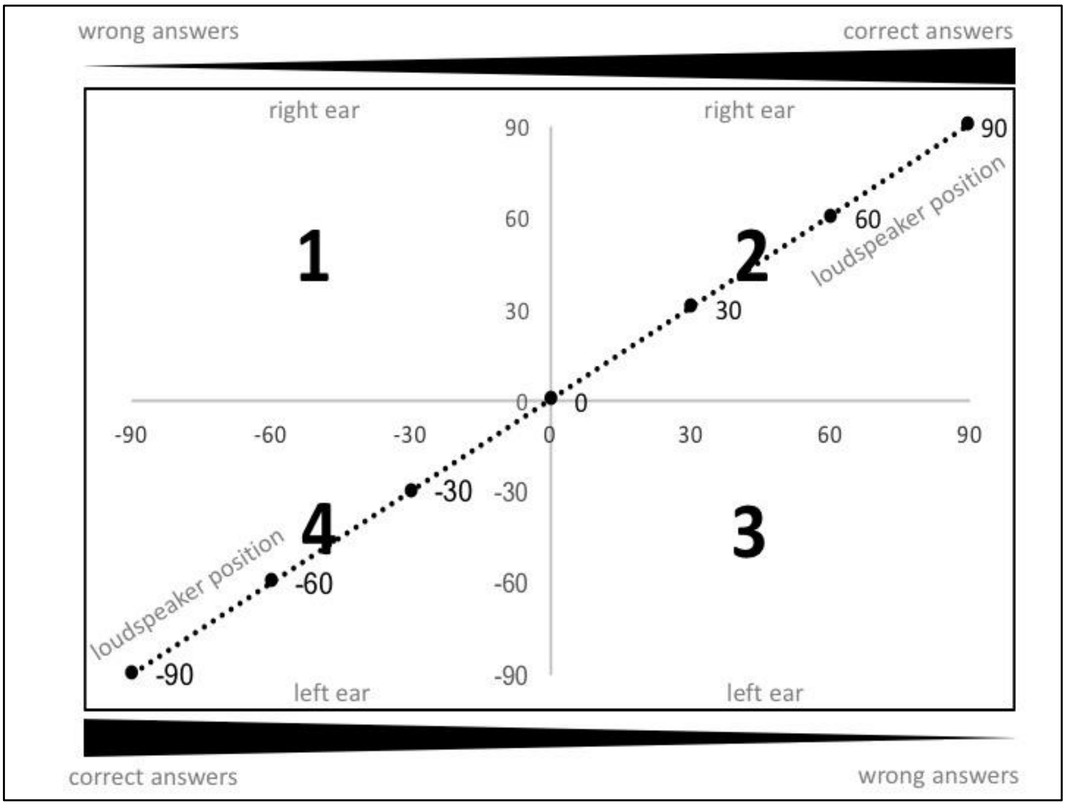

Figure 4 Explanation of the visualization- sound localization.

Ten volunteers were tested to evaluate the RMSE and the bias in bilateral normal hearing. Only one had two mistakes with only 30° deviation to the presented speaker, which means that in 42 items presented only 2 mistakes occoured in normal hearing subjects. This means a RMSE=0° and a bias=0°, nearly all presented signals correlate with the answers.

5.1.2.1 Individual Outcomes

To demonstrate the outcome of the sound localization test, the results of each patient are presented. To indicate the benefit, an individual trend line of the patients' answers (black line) versus the trend line of normal hearing (dashed line), is shown. The more correlation, the better the sound localization abilities of each patient is.

Patient 01; is a 65 year old female patient presenting sudden hearing loss on the right ear. At the date of testing, she had 2 years of experience with the CI. The PTA4-NH in this patient is 11,25dB and the PTA4-SSD before implantation was 120dB.

Figure 5 below describes the results of the sound localization test in the unaided condition. The patient reported hearing all the signals presented to her on the left, contralateral side with only one exception, which means inability of left- right localization. The RMSE= 74,5°, and the bias= -45°. The negative bias describes a large movement of the zero axis to the left earside of the patient.

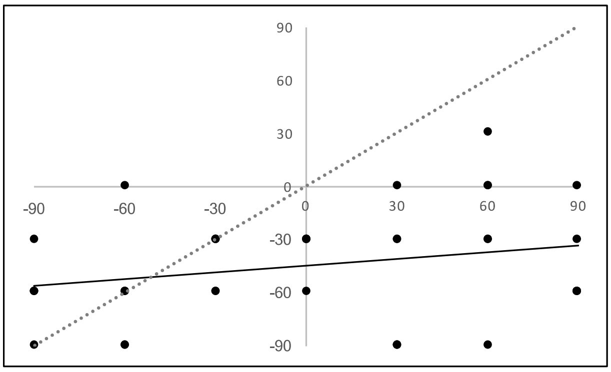

Figure 5 Sound localization results SSD of P_01.

Figure 6 below describes the results of the sound localization test in the SSD-CI aided condition. With the activated CI, the patient was able to localize sound much better. Signals presented to her from her right side were correctly localized. The trend line of normal hearing and the individual trend line are very close to each other. The RMSE= 32,4° and the bias= 0,7°.

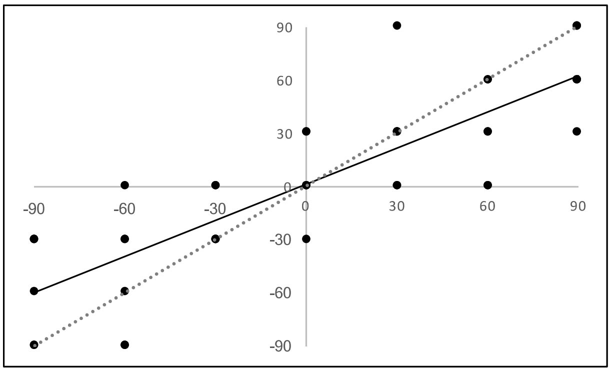

Figure 6 Sound localization results SSD-CI of P_01.

Patient 02; is a 59 year female patient presenting sudden hearing loss on the left ear. At the date of testing, she had two years of experience with the CI. The PTA4-NH in this patient is 10dB and the PTA4-SSD before implantation was 111,3dB.

Figure 7 below describes the results of the sound localization test in the condition of untreated SSD. The patient reported hearing most of the presented signals on her right side. Only a few signals have been located 30° left from the 0° axis. The RMSE= 54°, and the bias= 24,3°. The positive bias describes a movement of the zero axis to the right earside of the patient.

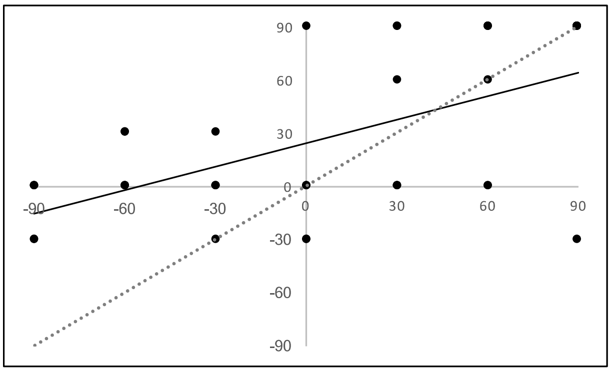

Figure 7 Sound localization results SSD of P_02.

Figure 8 below describes the results of the sound localization test in the SSD-CI aided condition. With the CI activated, the patient was able to localize sound much better. Signals presented to her from her left side were correctly localized, but not exactly assigned to the correct speaker. The trend line of normal hearing and the individual trend line are parallel to each other, which means that sound can be localized, if it comes from the right or from the left. The RMSE= 43,7° and the bias= -27,9°.

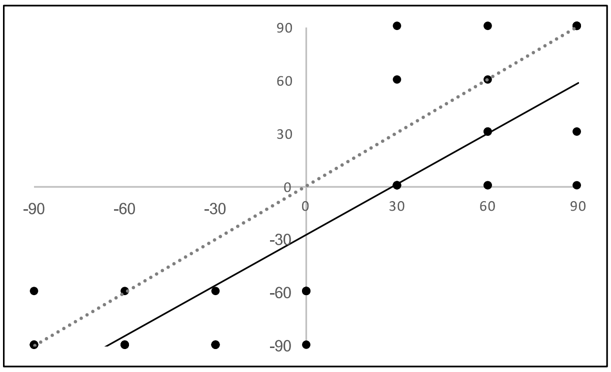

Figure 8 Sound localization results SSD-CI of P_02.

Patient 03; is a 19 year old female patient presenting with progredient hearing loss on the right ear. At the date of testing, she had one year of experience with the CI. The patient used conventional hearing aids previously, but the hearing threshold levels progressivley worsend. The PTA4-NH in this patient is 3,8dB and the PTA4-SSD before implantation was 78,8dB.

Figure 9 below describes the results of the sound localization test in the condition of unaided SSD. The patient reported, that locating the signals was not possible. Most of the signals were identified on the left side, but there were also big differences between presented signals and the individual answers. The RMSE= 76,8°, and the bias= -25°. The negative bias describes a large movement of the zero axis to the left earside of the patient.

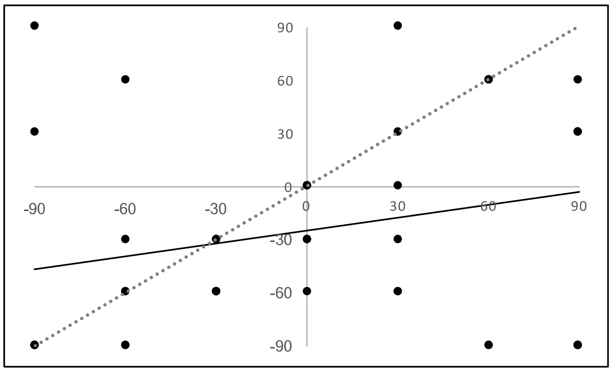

Figure 9 Sound localization results SSD of P_03.

Figure 10 below describes the results of the sound localization test in the SSD-CI aided condition. With the CI activated, the patient was able to localize the differece of right and left signals. The trend line of normal hearing and the individual trend line are very close to each other, but there are also differences in the answers of 60° to the left and to the right earside. The RMSE= 33,4° and the bias= 1,4°.

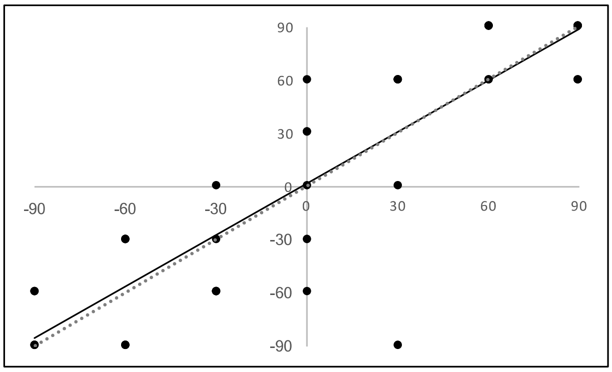

Figure 10 Sound localization results SSD-CI of P_03.

Patient 04; is a 53 year old female patient presenting with sudden hearing loss on the right ear. At the date of testing, she had five years experience with the CI. The PTA4-NH in this patient is 17,5dB and the PTA4-SSD before implantation was 90dB.

Figure 11 below describes the results of the sound localization test in the condition of unaided SSD. The patient reported, that localization was not possible. The figure shows that the answers are spread in a wide range to the norm line and only a few signals have been located correctly with a RMSE of 66,4°, and a bias of -5,7°. The heterogeneity of the answers is reflected in the big score of the RMSE and the negative bias describes the trend of localization to the left earside.

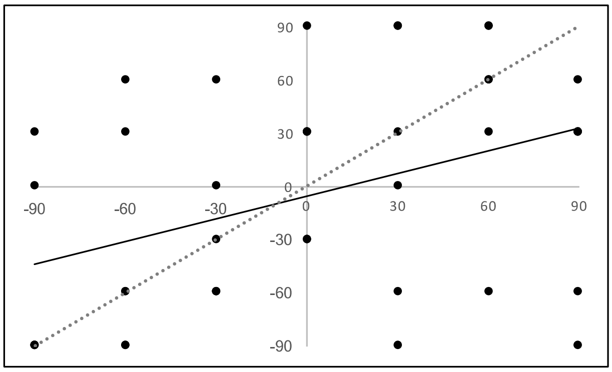

Figure 11 Sound localization results SSD of P_04.

Figure 12 below describes the results of the sound localization test in the SSD-CI aided condition. With the CI activated, the patient was able to localize sound much better. Signals presented to her from her right side were correctly localized, but the loudspeaker was not exactly identified. The answers show that a lot of signals presented on the left side have been localized to the right. The RMSE= 42,2° and the bias= 17,1°.

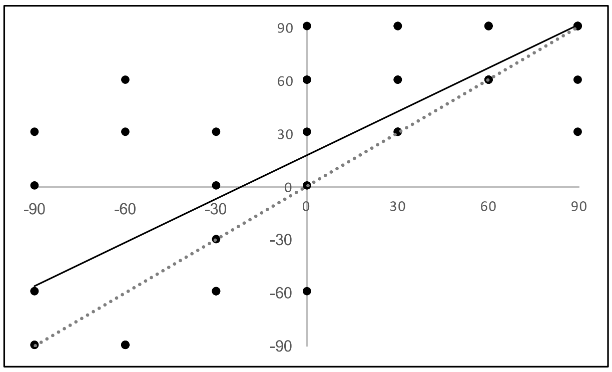

Figure 12 Sound localization results SSD-CI of P_04.

Patient 05; is a 52 year old female patient presenting with sudden hearing loss on the left ear. At the date of testing, she had one year of experience with the CI. The PTA4-NH in this patient is 12,5dB and the PTA4-SSD before implantation was 65dB. The lower frequencies in the left ear were much better than the higher frequencies, being the reason for the PTA4 above 70dB.

Figure 13 below describes the results of the sound localization test in the condition of unaided SSD. The patient reported hearing all the signals presented to her, on the right side with only two exceptions, which means a left- right localization impairment. The personal trend line did not correlate to the normative trend line. The RMSE= 68,8°, and the bias= 39,3°.

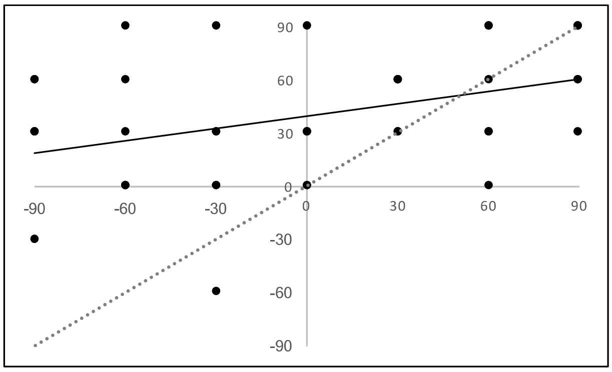

Figure 13 Sound localization results SSD of P_05.

Figure 14 below describes the results of the sound localization test in the SSD-CI aided condition. With the CI activated, the patient was able to localize the direction of signals. The trend line of normal hearing and the individual trend line are close to each other. The RMSE= 34° and the bias= -10°.

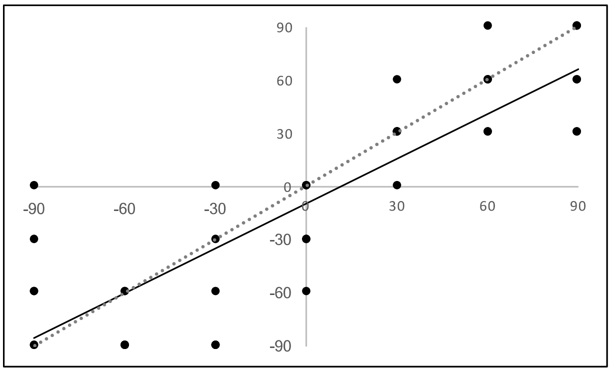

Figure 14 Sound localization results SSD-CI of P_05.

Patient 06; is a 51 year male patient presenting sudden hearing loss on the left ear. At the date of testing, he had one year of CI experience. The PTA4-NH in this patient is 7,5dB and the PTA4-SSD before implantation was 112,5dB.

Figure 15 below describes the results of the sound localization test in the unaided SSD condition. A lot of signals presented on the left side have been localized on the right earside, with only a few signals localized correctly. The bias disribes a trend to the right side in relation to the 0° axis. The normal hearing trend line and the individual trend line cross each other at 30°. The RMSE= 60,2°, and the bias= 17,9°.

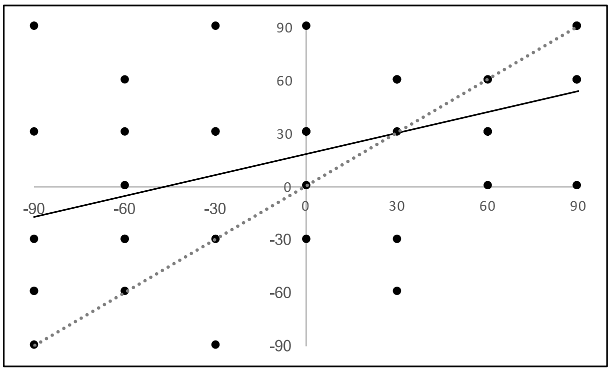

Figure 15 Sound localization results SSD of P_06.

Figure 16 below describes the results of the sound localization test in the SSD-CI aided condition. With the CI activated, the patient was able to localize sound much better. Signals presented to him from his right side were correctly localized on the same side. The answers on the right side are much closer to the normative data set compared to the left side. The RMSE= 31,4° and the bias= -11,4°.

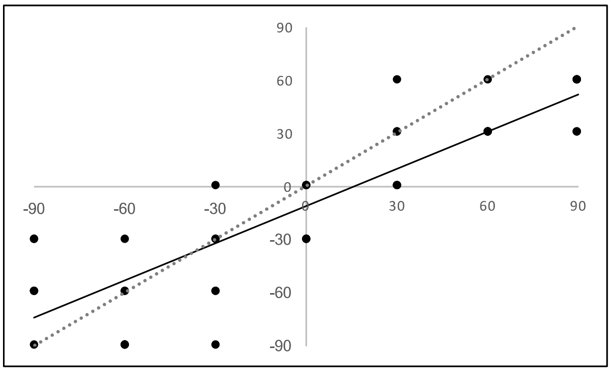

Figure 16 Sound localization results SSD-CI of P_06.

Patient 07; is a 21 year old female patient presenting a hearing loss since her childhood on the right ear. At the date of testing, she had two years of experience with the CI. The PTA4-NH in this patient is 8,8dB and the PTA4-SSD before implantation was 77,5dB.

Figure 17 below describes the results of the sound localization test in the SSD unaided condition. This patients outcomes were better, compared to other patients. The individual trend line shows rudeimental ability of left-right localization. The analysis of the localization shows that a few right signals have been localized more than 90° to the left. The RMSE= 52°, and the bias= -14,3°.

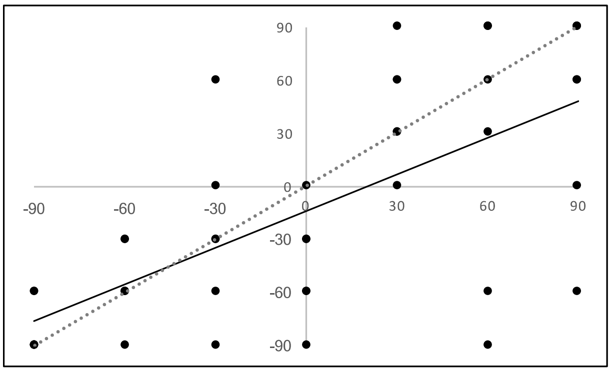

Figure 17 Sound localization results SSD of P_07.

Figure 18 below describes the results of the sound localization test in the SSD-CI aided condition. With the CI activated, the patient was able to localize sound much better. Signals presented to her from her right side were correctly localized on the same side. The trend line of normal hearing and the individual trend line are very close to each other. The RMSE= 22,2° and the bias= 6,4°.

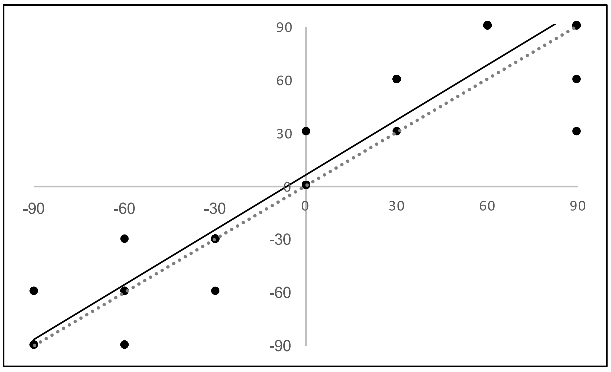

Figure 18 Sound localization results SSD-CI of P_07.

Patient 08; is a 72 year old female patient presenting with sudden hearing loss on the left ear. At the date of testing, she had four years of experience with the CI. The PTA4-NH in this patient is 18,8dB and the PTA4-SSD before implantation was 72,5dB.

Figure 19 below describes the results of the sound localization test in the SSD unaided condition. The patient reported that a left- right localization is not possible for her. The individual trend line shows that the answers, which she had given are very far away from the presented signal. The present figure also shows that the signals from the left have been located left and a lot of signals from the right have also been located left. The RMSE= 63,8°, and the bias= -2,9°.

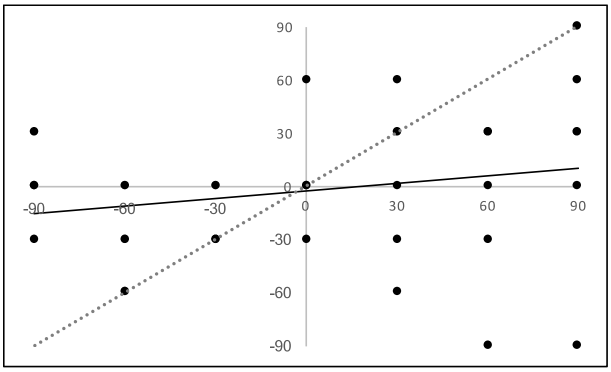

Figure 19 Sound localization results SSD of P_08.

Figure 20 below describes the results of the sound localization test in the SSD-CI aided condition. With the CI activated, the patient was able to localize sound much better. Signals presented from her right side were correctly localized on the same side. She localized signals by tend 30° more right than the signal was presented. This is in alignment with the individual bias, describing the same heterogeneity in results from a negative- to a positive bias. The RMSE= 32,4° and the bias= 10,7°.

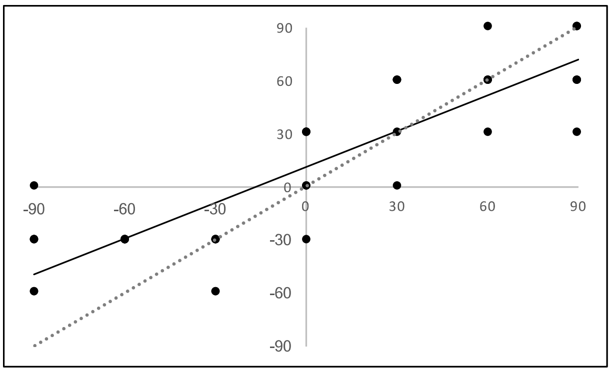

Figure 20 Sound localization results SSD-CI of P_08.

Patient 09; is a 63 year old female patient presenting with sudden hearing loss on the left ear. At the date of testing, she had less than one year of experience with the CI. The PTA4-NH in this patient is 11,3dB and the PTA4-SSD before implantation was 91,3dB.

Figure 21 below describes the results of the sound localization test in the SSD unaided condition. The patient reported hearing all the signals presented to her, on the left side with only two exceptions, which means that a left- right localization is not possible. A localization among the 0° axis is hardly working, which the high negative bias also describes. The RMSE= 59°, and the bias= -20°.

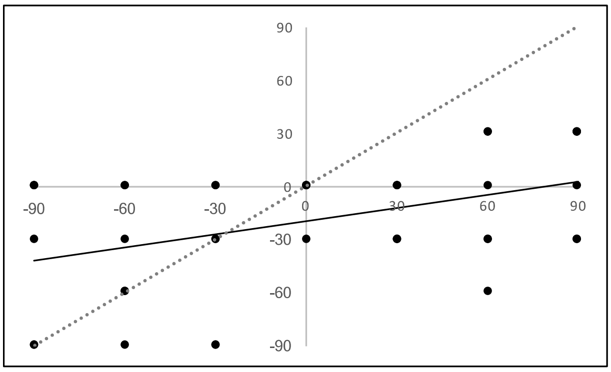

Figure 21 Sound localization results SSD of P_09.

Figure 22 below describes the results of the sound localization test in the SSD-CI aided condition. With the CI activated, the patient was not able to improve sound localization. Most of the signals, independent whether they have been presented to her left or to her right, were located on the left. There is only a minimal improvement in the RMSE. The RMSE= 57,6° and the bias= -40,7°.

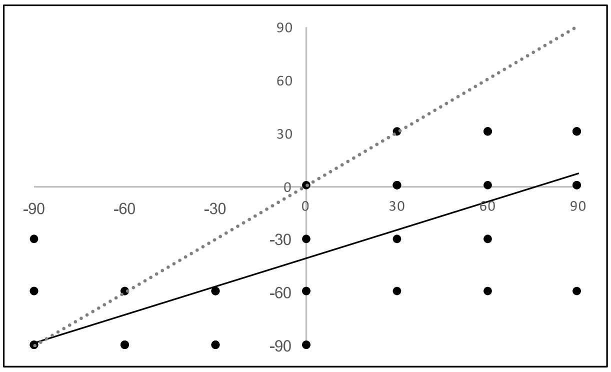

Figure 22 Sound localization results SSD-CI of P_09.

Patient 10; is a 25 year old male patient presenting with total deafness following an accident with a fracture to the mastoid on the left. At the date of testing, he had four years of experience with the CI. The PTA4-NH in this patient is 11,3dB and the PTA4-SSD before implantation was 120dB.

Figure 23 below describes the results of the sound localization test in the SSD undaided condition. The patient reported that a localization without the CI is not possible. All given answeres have been far away from the presented speaker. Right signals have been heard left and vice versa. There is no consistency in the bias. The RMSE= 72,5°, and the bias= 5°.

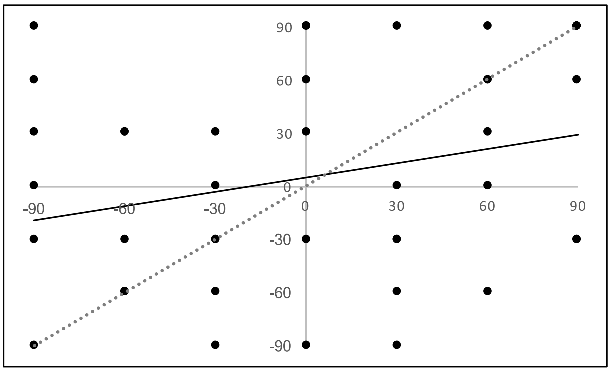

Figure 23 Sound localization results SSD of P_10.

Figure 24 below describes the results of the sound localization test in the SSD-CI aided condition. With the CI activated, the patient was able to localize sound much better. Signals presented on one side have been localized on the same side. The trend line of normal hearing and the individual trend line are much closer to each other compared to the unaided condition. The RMSE= 40,6° and the bias= 12,1°.

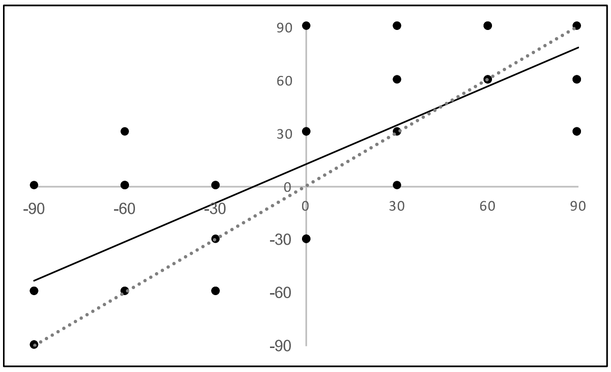

Figure 24 Sound localization results SSD-CI of P_10.

5.1.2.2 Study cohort right side

To analyse the results of the sound localization for the four patients presenting SSD on the right side, the mean of the RMSE and the bias were calculated.

The mean bias showed a big dislocation to the left normal hearing ear. The bias in the SSD unaided condition was -22,5° compared to the SSD-CI aided condition, resulting in an adjustment in localization with the bias turning to positive with 6,4° on the right side.

The mean of the RMSE shows that there is a big difference between the two conditions. In unaided SSD the RMSE was 67,4° and in the aided SSD-CI RMSE improves to 33,8°. This results an improvement of 33,6° in the RMSE.

5.1.2.3 Study cohort left side

The other six patients presented SSD on the left side. The analysis of the mean shows that in the condition of unaided SSD no dislocation to the normal hearing ear is present. The bias in unaided SSD was 10,6° compared to the normal hearing right side. In the SSD-CI aided condtion the bias was -11,2°. Patients with an activated CI localize more to the left side.

The RMSE for the unaided patients presenting SSD on the left was 63° compared to SSD-CI aided condition with a RMSE iof 40°. The results show a big difference between the unaided and aided CI condition. The RMSE results improved to 23°.

5.1.2.4 Overall Outcomes

The significance of the improvement of the mean RMSE comparing the undaided SSD with the aided SSD-CI condition was calculated. In the unaided SSD condition the RMSE was 64,7° and in the SSD-CI aided condtion the RMSE was 37,5°, resulting in a statistically significant improvement in sound localization in the condition SSD-CI aided condition $p<0,05$ (t-test, see Appendix A).

5.2 Subjective Benefit (Quality of Life)

5.2.1 APHAB Questionnaire

Figure 25 describes the outcomes of the APHAB questionnaire of the ten analysed subjects. The x-axis presents the different subscales comparing the unaided SSD with the SSD-CI aided condtion. The y-axis gives the mean scores for EC, BN, RV, and AV from 0% -100%. The lower the percentage, the lower the handicap. The APHAB score is the mean result of all answers. EC contains the mean results of the subscale ease of communication. BN contains the mean results of questions with the topic of background noise. RV is the mean result of the answered questions to the topic of reverberation and AV is the mean result of the answers to question which deal with aversiveness to sound.

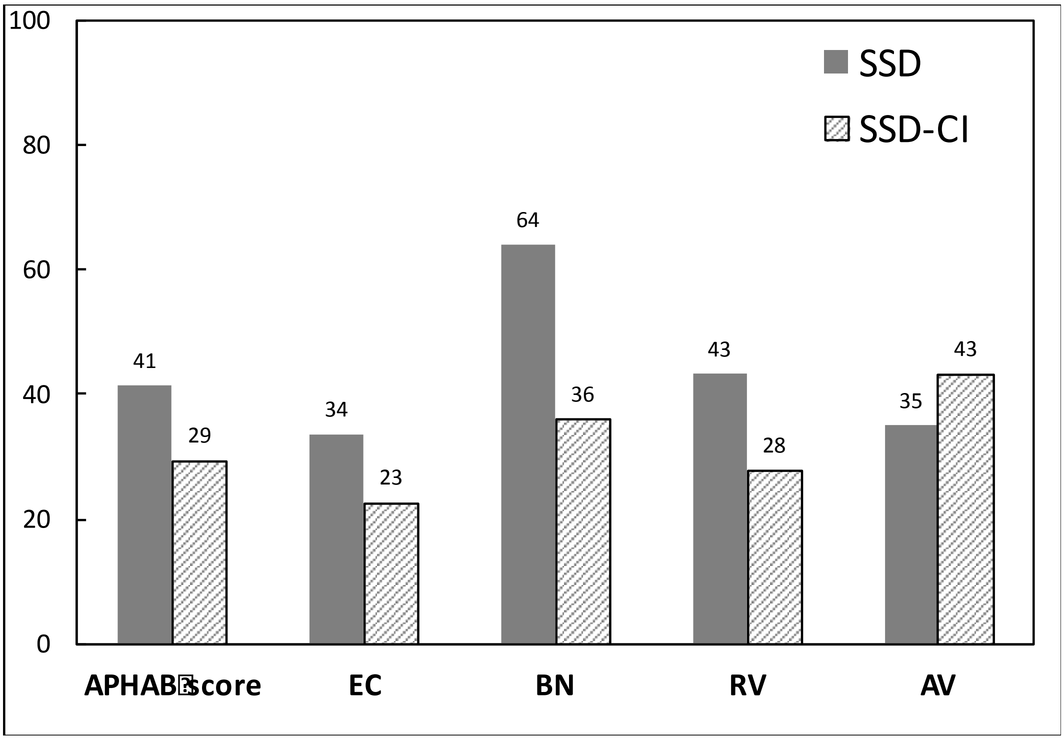

Figure 25 Results APHAB questionnaire.

Ease of Communication (EC scale) includes the questions: 4, 10, 12, 14, 15, 23.

The subscale EC deals with difficulties in conversations in easy listening environments like, hearing conversations at home with one family member or interviewing or answering questions in a small office. Asking people in a one-on-

one communication. And at least following and understanding the conversation with a doctor in an examination room [34].

The results of this subscale shows that for the ten patients in the unaided SSD condition, a handicap of 34% can be measured, whereas in SSD-CI aided conditione the handicap reduces to 23%, resulting in an improvement of 11% for EC.

Background Noise (BN scale) includes the questions: 1, 6, 7, 16, 19, 24. Questions 1, 16, 19, are evaluated in reversed order, which means that an “A”, turns from a positive outcome “every time” into a “G” which means “never”, a negative result.

This subscale deals with questions to the topic of conversations in difficult listening environments due to background noise. Difficult situations are for example following the news in the radio while driving the car and other family members are having a conversation. Another topic is the understanding and ability to follow conversations, even when several people are talking at the same time [34].

The outcomes of this subscale resulted in the unaided SSD condition to a handicap score of 64%. In the SSD-CI aided condtion this score reduces to 36%, resulting in an improvement of 28% when the CI is activated.

Reverberation (RV scale) includes the questions: 2, 5, 9, 11, 18, 21. Questions 9 and 11 are evaluated in reversed order.

The subscale RV deals with the topic of speech understanding in different spatial/reverberate conditions, such as difficulties listening to a lecture, or having trouble understanding a dialoge in theater or in a movie. Another question deals with the understanding in large empty rooms, such as in a church [34].

The evaluation of the RV results showed that the unaided SSD group exhibited a handicap score of 43%, which improved in the SSD-CI aided condition to 28%. With the CI activated the reveverabtion improvement is 15%.

Aversiveness (AV scale) includes the questions: 3, 8, 13, 17, 20, 22.

This subscale deals with questions regarding unexpected and uncomfortable loud sounds, like a smoke detector or alarm bells. Aversivenss to sound is also evaluated by the handling of traffic noises, screeching tires, the sound of construction work or suddenly appearing loud noises like a fire engine sirens and wheter those are uncomfortable loud for the CI patient [34].

The results of the AV subscale showed a handicap score of 35% in the SSD unaided condition SSD. The SSD-CI aided condtion AV score was calcutated at 43% resulting in a mean deterioration between the aided and unaided condition of 8%. Which means, that unexpected loud sounds are more uncomfortable when CI is activated compared to the unaided condition.

APHAB score is the mean of all answers. The results show that in the unaided SSD condition the handicap score is 41% compared to the SSD-CI aided condtion with 29%, resulting in an overall improvement of 12%. The t-Test resulted in a significant difference of $p<0,05$ (t-test, see Apendix A) .

5.2.2 SSQ12 Questionnaire

Figure 26 describes the results of the SSQ12 questionnaire. The x-axis describes the different subscales. The y-axis shows the outcomes per subscale and measured condition, unaided SSD vs SSD-CI aided condition, in %.

The lower % outcome, the less pronounced the handicap is perceived. The answering scale for each question ranges from zero to ten. Therefore the means are multiplied by ten and to calculate the handicap score, the mean outcome per subscale is substracted from the maximum of 100%.

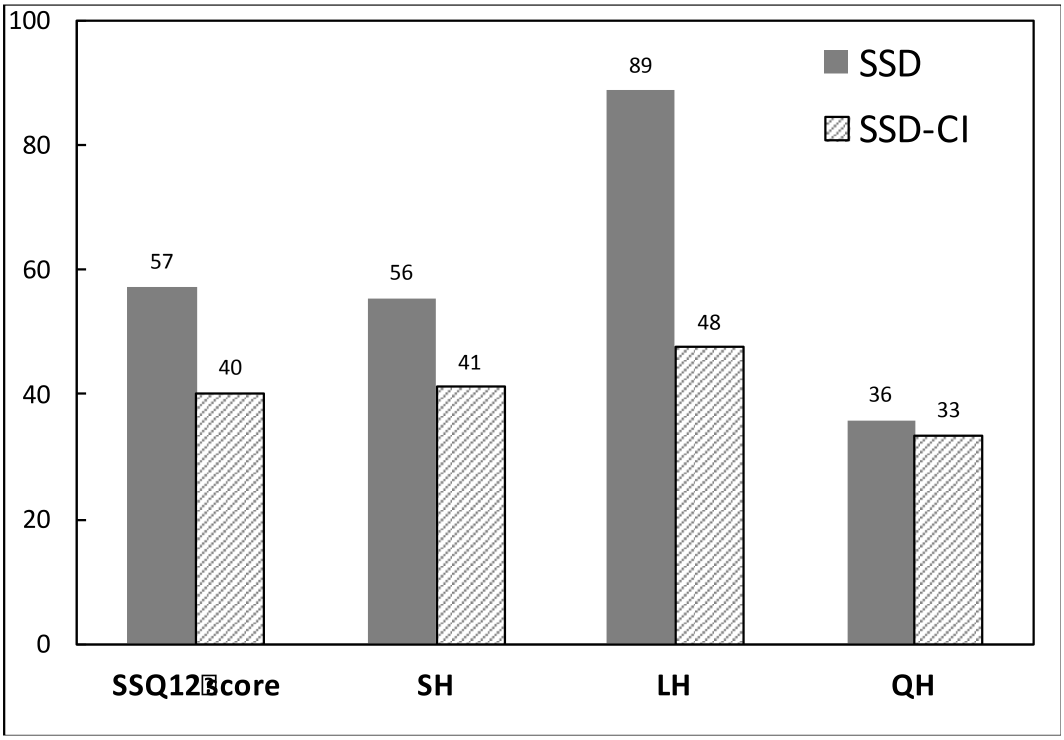

Figure 26 Results SSQ12 questionnaire.

Speech understanding (SH scale) includes the questions: 1, 2, 3, 4, 5.

SH deals with the topic of speech understanding in difficult conditions. This subscale asks questions whether a patient is able to follow a conversation while a TV running or if he/she experiences troubles understanding a conversation or understanding the news on TV while another person is talking at the same time. Another question asks regarding the difficulties understanding a conversation in a room, while a lot of people are talking to each other [35].

The subscale SH resulted in a handicap of 56% in the unaided SSD condition which improved in the SSD-CI aided condition to a handicap score of 41%. Resulting in an improvement of 15% in speech understanding in difficult situations.

Sound localization (LH scale) includes the questions: 6, 7, 8.

LH examines the topic of sound localization. This subscale includes questions such as identifying where a bus or truck comes from, or if it is coming towards you, or if it is possible to tell immediately where a dog barks etc. [35].

The LH subscale mean shows that in undaided SSD the handicap score is 89% and in the SSD-CI aided condition the score is 48%, resulting in an improvement of 41% in sound localization.

Quality of hearing (QH scale) includes the questions: 9, 10, 11, 12.

QH deals with the topic of quality of hearing. The subscale QH includes questions regarding how sounds are perceived. If hearing more than one sound at the same time makes it impossible to separate them. Another question is whether it is possible to identify an instrument by playing its notes. Also important how much effort the patient has to put towards listening and understanding things [35].

The QH subscale resulted in an handicap score in the SSD undaided condition of 36%. The QH score for the SSD-CI aided condtion revealed a score of 33%, resulting in an improvement of 3%.

SSQ12 score is the overall mean. The results show that in the unaided SSD condition the handicap score is about 57% wheras in the SSD-CI condition the score improved to 40% resulting in a benefit of 17%. The t-Test revealed a statistically significance of $p<0,05$ (t-test, see Apendix A).

6 Discussion

The literature review has shown that only a few studies exist to the topic of sound localization in Single Sided Deafness after Cochlear implantation. The test procedures of the present SSD-CI study of the ENT-Department of the University Hospital St. Pölten were base on these studies. The number of tested patients (n=10) might appear insufficient, but given the rather rare condtion or better to say the relatively narrow indication criteria for patients included makes the outcomes as well as the interpretation worthwile. The rather strict inclusion criteria of manufacturer MED-EL were followed for this study. Some of the identified citations also characterise SSD with a mild hearing loss of PTA4<30dB in the hearing ear [27]. The literature describes normal hearing by a hearing level of up to 20dB [15]. The mean of the here described normal hearing patients (PTA4-NH) was 11,25dB.

Another important inclusion criteria was the period between implantation and testing had to be longer than six months. This was relevant, for the rehabilitation of the patients with the CI system. In the first months after the CI surgery the patients have to become aquainted with the new situation and have to learn and train how to understand speech with a CI. Five patients with an Audio Processor of a previous generation received a fitting with the new Sonnet AP and were tested accordingly. They had only a short period of time to experience the new fitting. In next studies patients should have more time to familiarise and get more experience with a new generation of an AP, to minimize the bias.

The results of the speech understanding in noise with the OLSA in the condition speech and noise from the front, S0N0 showed a significant improvement $p<0,05$. The difference in the condition unaided SSD and SSD-CI aided outcomes was 1,95dB, resulting in an improvement of almost 32%.

It would be interesting if speech understanding in noise tested in other conditions would also result in significant improvements. Arndt et al. describes in their study the head shadow effect in different conditions depending on the setting of the loudspeakers. If a signal is originated from the right, the head works like a shadow for the left ear [27]. If the signal comes from the front and the noise from the side of the deaf ear ($S0N_{SSD}$)- speech understanding should be easier than in the condition of signal from the front and noise form the side of normal hearing ($S0N_{NH}$). Both conditions should be measured in the two variants in unaided SSD and in SSD-CI aided condition, to evaluate all relevant informations. These test conditions should be added to the test protocol for the next SSD-CI studies to get further information about speech understanding in noise and the head shadow effect.

A control group comprising ten bilateral normal hearing subjets performed sound localization tests to ensure the feasibility of the present test setting of seven speakers. The results clearly proofed the practicability of such a test for normal hearing subjects.

The results of the unaided SSD patients showed, that most of the signals were located on the normal hearing side. Patients described that a sound localization without activated AP was hardly possible and most of the answers were guesses where the signal originated from.

In the SSD-CI aided condition the results clearly differ to the unaided SSD condition. The aided patients perform much better and localization sound was easier for them. Patients describe that in every day's life the same effect occurs. With the activated AP, the patient describe that it is possible again to localize if a car comes from the left or from the right, or from which side a person speaks from.

Investigating the individual results further, the outcome of patient 09 is not as good as the results of all other patients. The patient presented the SSD on the left side and had less than one year of experience with the CI. Given this it may be relevant to know, that the fitting varies a lot from one appointment to the next. The localization tests show that in the unaided SSD condition most of the signals were located on the deaf side, in the condition of SSD-CI aided; only a few more signals were located on the right side. The patient herself explains the results due to the fact that she is used to concentrate on the deaf ear.

The RMSE mean results all answers for all patients resulted in a significant improvement in sound localization ($p<0, 05$).

The two different questionnaires were selected because they are validated and available in different languages as well as being widely cited in the literature.

The results of the APHAB questionnaire show that the biggest difference and improvement, was found in the category BN. For all ten patients the individual, subjective assessment in situations of understanding when there is a background noise, is 28% better in the SSD-CI aided condition. The category AV, dealing with questions regarding unexpected loud signals, showed that the patients rated the condition of unaided SSD better than with activated CI. The patients explained this due to the loud signals; especially in high frequencies, were perceived as more uncomfortable. This may change by reducing the MCL-Level in the high frequencies in the next fitting session.

The mean score of all answers shows that there is a significant improvement in the APHAB score and its handicap index when CI is activated ($p<0,05$).

The results of the second questionnaire the SSQ12 resulted in similar outcomes. The SSQ12 separates sound localization LH into several categories. The individual answers are in correlation with the sound localization test, were the localization of sound was better in the SSD-CI aided condition.

The category QH shows that the quality of sounds does not really change between the different conditions, which should be like that. The quality of different sounds does not have to change when CI is activated.

A look at the SSQ12 score showed an reduced handicap index of 17%. The mean score of all answers also shows a significant improvement in the SSD-CI aided condition ($p<0,05$).

Patients reported that the sound localization test shows impressively the improvement and should be used for the rehabilitation scheme, to motivate the patients with their individual outcome.

They also reported that their individual quality of life has improved after CI implantation, which is confirmed by the subjective outcomes of the two questionnaires administred.

7 Conclusion

The results for the eavaluated SSD-CI patients showed a statistically significant ($p<0,05$) improvement in all tested categories: (1) speech understanding in noise with the OLSA in the condition S0N0, (2) sound localization test with seven speakers in a semicircle in front of the patient, and in (3) the two different questionnairs, the APHAB and the SSQ12.

The new treatment of CI in SSD should be the method of choice to rehabilitate patients hearing, given the medical preconditions for such an operation exist.

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Appendix

A. SPSS Results

Gruppenstatistik

	Versorgung	H	Mittelwert	Standardabweichung	Standardfehler Mittelwert
OLSA	SSD	10	-3,3500	2,05494	,64983
	SSD-CI	10	-5,2900	1,99469	,63078
Richtungshören	SSD	10	64,7462	8,54924	2,70351
	SSD-CI	10	37,4932	9,99848	3,16180
APHAB	SSD	10	41,3121	13,28681	4,20166
	SSD-CI	10	29,3792	10,10866	3,19664
SSQ12	SSD	10	4,2650	,95527	,30208
	SSD-CI	10	5,9677	1,26267	,39929

Test bei unabhängigen Stichproben

		Levene-Test der Varianzgleichheit		T-Test für die Mittelwertgleichheit						
									95% Konfidenzintervall der Differenz	
		F	Sig.	t	df	Sig. (2-seitig)	Mittelwertdifferenz	Standardfehlerdifferenz	Unterer	Oberer
OLSA	Varianzgleichheit angenommen	,201	,659	2,142	18	,046	1,94000	,90562	,03735	3,84265
	Varianzgleichheit nicht angenommen			2,142	17,984	,046	1,94000	,90562	,03723	3,84277
Richtungshören	Varianzgleichheit angenommen	,123	,730	6,551	18	,000	27,25303	4,16004	18,51311	35,99294
	Varianzgleichheit nicht angenommen			6,551	17,576	,000	27,25303	4,16004	18,49798	36,00808
APHAB	Varianzgleichheit angenommen	,956	,341	2,260	18	,036	11,93292	5,27943	,84124	23,02460
	Varianzgleichheit nicht angenommen			2,260	16,804	,037	11,93292	5,27943	,78438	23,08145
SSQ12	Varianzgleichheit angenommen	,681	,420	-3,401	18	,003	-1,70267	,50069	-2,75457	-,65076
	Varianzgleichheit nicht angenommen			-3,401	16,760	,003	-1,70267	,50069	-2,76018	-,64515

B. APHAB Questionnaire

APHAB – FORMULAR A

Anweisungen:

Bitte wählen Sie die Antwort, die ihrer alltäglichen Erfahrung am nächsten kommt. Wenn Sie eine bestimmte Situation nicht erlebt haben, stellen Sie sich vor, wie Sie in einer ähnlichen Situation antworten würden.

A Immer (99%)
B Fast immer (87%)
C Häufig (75%)
D In der Hälfte der Fälle (50%)
E Gelegentlich (25%)
F Selten (12%)
G Nie (1%)

		Ohne Hörgeräte	Mit Hörgeräten
1.	Wenn ich in einem belebten Lebensmittelgeschäft mit der Kassiererin spreche, kann ich dem Gespräch folgen.	A B C D E F G	A B C D E F G
2.	Es entgeht mir viel Information, wenn ich einen Vortrag anhöre.	A B C D E F G	A B C D E F G
3.	Unerwartete Geräusche, wie einen Rauchmelder oder eine Alarmanlage, empfinde ich als unangenehm.	A B C D E F G	A B C D E F G
4.	Ich habe Schwierigkeiten, zu Hause einem Gespräch mit einem Familienangehörigen zu folgen.	A B C D E F G	A B C D E F G
5.	Ich habe Mühe, den Dialog in einem Film oder im Theater zu verstehen.	A B C D E F G	A B C D E F G
6.	Wenn ich am Autoradio die Nachrichten höre und Familienmitglieder sich dabei unterhalten, habe ich Mühe, die Nachrichten zu verstehen.	A B C D E F G	A B C D E F G
7.	Wenn ich mit mehreren Personen beim Essen sitze, und ich mich mit einer Person unterhalten möchte, ist es für mich schwierig, zu verstehen.	A B C D E F G	A B C D E F G
8.	Verkehrslärm ist mir zu laut.	A B C D E F G	A B C D E F G
9.	Wenn ich mit jemandem spreche, der sich am andern Ende eines grossen leeren Raumes befindet, verstehe ich seine Worte.	A B C D E F G	A B C D E F G
10.	Wenn ich in einem kleinen Büroraum Fragen stelle oder beantworte, habe ich Schwierigkeiten, dem Gespräch zu folgen.	A B C D E F G	A B C D E F G

HARL
Hearing Aid Research Lab.

A	Immer (99%)
B	Fast immer (87%)
C	Häufig (75%)
D	In der Hälfte der Fälle (50%)
E	Gelegentlich (25%)
F	Selten (12%)
G	Nie (1%)

		Ohne Hörgeräte	Mit Hörgeräten
11.	Wenn ich im Kino oder Theater bin und die Leute um mich herum flüstern und mit Papier rascheln, kann ich dem Dialog immer noch folgen.	A B C D E F G	A B C D E F G
12.	Wenn ich mich mit einem Freund in einer ruhigen Umgebung unterhalte, habe ich Schwierigkeiten, zu verstehen.	A B C D E F G	A B C D E F G
13.	Die Geräusche von fliessendem Wasser, wie eine Toilettenspülung oder Dusche, sind mir unangenehm laut.	A B C D E F G	A B C D E F G
14.	Wenn ein Sprecher zu einer kleinen Gruppe spricht und alle ruhig zuhören, muss ich mich anstrengen, um zu verstehen.	A B C D E F G	A B C D E F G
15.	Wenn ich mit meinem Arzt im Untersuchungszimmer spreche, fällt es mir schwer dem Gespräch zu folgen.	A B C D E F G	A B C D E F G
16.	Ich kann einer Unterhaltung folgen , auch wenn mehrere Personen gleichzeitig sprechen.	A B C D E F G	A B C D E F G
17.	Baulärm ist mir unangenehm laut.	A B C D E F G	A B C D E F G
18.	Es ist für mich schwierig, zu verstehen, was bei Vorträgen oder in der Kirche gesprochen wird.	A B C D E F G	A B C D E F G
19.	Ich kann mich mit anderen unterhalten, wenn wir in einer Menschenmenge sind.	A B C D E F G	A B C D E F G
20.	Die Sirene eines nahen Feuerwehrfahrzeugs ist so laut, dass ich meine Ohren zuhalten muss.	A B C D E F G	A B C D E F G
21.	Im Gottesdienst kann ich die Worte der Predigt verstehen.	A B C D E F G	A B C D E F G

A	Immer (99%)
B	Fast immer (87%)
C	Häufig (75%)
D	In der Hälfte der Fälle (50%)
E	Gelegentlich (25%)
F	Selten (12%)
G	Nie (1%)

		Ohne Hörgeräte	**Mit Hörgeräten**
22.	Das Geräusch von quietschenden Reifen ist mir unangenehm laut.	A B C D E F G	A B C D E F G
23.	Ich muss den Gesprächspartner bitten, sich zu wiederholen, wenn wir uns zu zweit in einem ruhigen Raum unterhalten.	A B C D E F G	A B C D E F G
24.	Ich habe Mühe, andere zu verstehen, wenn gleichzeitig eine Klimaanlage oder ein Ventilator läuft.	A B C D E F G	A B C D E F G

C. SSQ12 Questionnaire

StudyTitle:
SSD-CI

Study ID:

SPEECH, SPATIAL AND QUALITIES OF HEARING SCALE (SSQ12)

SPRACHE, RÄUMLICHES HÖREN UND HÖRQUALITÄT

Dieser Fragebogen ist vom Patienten selbst auszufüllen!

Anleitung zum Ausfüllen des Fragebogens

Die folgenden Fragen betreffen Ihre Erfahrungen und Fähigkeiten in verschiedenen Situationen zu hören und zu verstehen.

Für jede Frage machen Sie bitte auf einer Skala von 0 bis 10 ein Zeichen, vorzugsweise einen Schrägstrich (/). Achten Sie bitte darauf, dass der Strich die Skala kreuzt, wie im Beispiel unten gezeigt. Wenn Sie eine „10" ankreuzen, bedeutet dies, dass Sie perfekt das machen können oder genau das erlebt haben, was in der Situation beschrieben ist. Wenn Sie eine „0" ankreuzen, bedeutet dies, dass Sie das in der Situation Geschilderte nicht machen können oder erlebt haben.

Dazu folgendes Beispiel: In Frage 1 wird danach gefragt, ob Sie eine andere Person verstehen können, ohne den Fernseher leise zu stellen. Wenn Sie gut in der Lage sind, die Person gut zu verstehen, machen Sie bitte ein Kreuz auf der rechten Seite der Skala. Wenn Sie ungefähr die Hälfte der Unterhaltung verstehen können, machen Sie bitte ein Kreuz in der Mitte der Skala und so weiter.

Wenn in einer Frage eine Situation beschrieben wird, die Sie nicht betrifft oder die sie nicht kennen, machen Sie bitte ein Kreuz bei „trifft nicht zu". Beantworten Sie die Fragen bitte so, wie Sie die jeweilige Situation mit Ihren Hörimplantaten erleben!

Richtig:	0 1 2 3 4 5 / 6 7 8 9 10
Falsch:	/ 0 1 2 3 4 5 6 7 8 9 10

Page 1 of 4

Heutiges Datum	

1. Sie sprechen mit einer anderen Person während der Fernseher im selben Raum läuft. Können Sie die andere Person, mit der Sie sprechen, verstehen, ohne den Fernseher leise zu stellen?
Überhaupt nicht 0 1 2 3 4 5 6 7 8 9 10 Perfekt
☐ Trifft nicht zu

2. Sie hören jemandem zu, der mit Ihnen spricht, während Sie gleichzeitig versuchen, der Nachrichtensendung im Fernsehen zu folgen. Können Sie beiden Personen folgen, was sie sagen?
Überhaupt nicht 0 1 2 3 4 5 6 7 8 9 10 Perfekt
☐ Trifft nicht zu

3. Sie unterhalten sich mit einer Person in einem Raum, in dem viele andere Leute sprechen. Können Sie der Person folgen, mit der Sie sprechen?
Überhaupt nicht 0 1 2 3 4 5 6 7 8 9 10 Perfekt
☐ Trifft nicht zu

4. Sie sind mit einer Gruppe von etwa fünf Personen in einem belebten Restaurant und Sie können jeden in der Gruppe sehen. Können Sie der Unterhaltung folgen?
Überhaupt nicht 0 1 2 3 4 5 6 7 8 9 10 Perfekt
☐ Trifft nicht zu

5.	Sie sind in einer Gruppe und die Unterhaltung wechselt von einer Person zur anderen. Können Sie der Unterhaltung mühelos folgen, wenn eine neue Person zu reden beginnt ohne den Anfang zu verpassen?

Überhaupt nicht 0 1 2 3 4 5 6 7 8 9 10 Perfekt

☐ Trifft nicht zu

6.	Sie sind im Freien. Ein Hund bellt laut. Können Sie sofort sagen, wo der Hund ist, ohne hinzuschauen?

Überhaupt nicht 0 1 2 3 4 5 6 7 8 9 10 Perfekt

☐ Trifft nicht zu

7.	Können Sie anhand des Geräusches sagen, wie weit ein Bus oder Lastwagen entfernt ist?

Überhaupt nicht 0 1 2 3 4 5 6 7 8 9 10 Perfekt

☐ Trifft nicht zu

8.	Können Sie anhand des Geräusches sagen, ob ein Bus oder Lastwagen Ihnen entgegen kommt oder sich entfernt?

Überhaupt nicht 0 1 2 3 4 5 6 7 8 9 10 Perfekt

☐ Trifft nicht zu

9. Wenn Sie mehr als ein Geräusch gleichzeitig hören, haben Sie den Eindruck, dass dies wie ein einziges Geräuschwirrwarr klingt?

Überhaupt nicht 0 1 2 3 4 5 6 7 8 9 10 Perfekt

☐ Trifft nicht zu

10. Wenn Sie der Musik zuhören, können Sie erkennen, welche Instrumente spielen?

Überhaupt nicht 0 1 2 3 4 5 6 7 8 9 10 Perfekt

☐ Trifft nicht zu

11. Klingen Alltagsgeräusche, die Sie leicht hören können, klar für Sie (nicht verschwommen)?

Überhaupt nicht 0 1 2 3 4 5 6 7 8 9 10 Perfekt

☐ Trifft nicht zu

12. Müssen Sie sich sehr stark konzentrieren, wenn Sie jemandem zuhören oder auf etwas Bestimmtes hören?

Überhaupt nicht 0 1 2 3 4 5 6 7 8 9 10 Perfekt

☐ Trifft nicht zu