

Do subjective voice handicap and vocal tract discomfort change within the first year of cochlear implant use?

Variieren subjektive Stimmbeeinträchtigungen und Beschwerden im Vokaltrakt innerhalb des ersten Jahres der Verwendung eines Cochlea Implantats?

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Abstract

Objectives: Hearing impairment can lead to changes in phonation and articulation. However, so far there are studies showing that this does not necessarily lead to a voice disorder. The change in hearing induced by cochlear implant (CI) is well established, whereas the effects on voice from the patient perspective have not been frequently assessed. Therefore, the main aim of this study was to examine subjective voice handicap and vocal tract discomfort in CI recipients and the relation with improvement in speech comprehension within their first year of CI use. Further, the influence of gender, vocal hygiene, voice usage and voice therapy was investigated.

Study Design: Prospective longitudinal study.

Methods: 83 adults (43 female and 40 male) between 24 and 82 years of age, who received a cochlear implant (CI) were investigated at first fitting (FF), at 3 months and at 12 months after FF. Voice-related subjective symptoms were assessed with the Vocal Tract Discomfort Scale (VTD), the internationally validated nine-item Voice Handicap Index (VHI-9i) and a self-developed questionnaire evaluating data regarding voice usage and hygiene, prior therapy and other influence factors like gender. Speech comprehension with the CI was assessed via Freiburger Speech Intelligibility Test (FBM) using monosyllables in a quiet environment. Subjective hearing abilities were assessed via the Speech, Spatial and Qualities of Hearing Scale (SSQ12) questionnaire. Descriptive statistics as well as One-Way Analysis of Variance (ANOVA) for Repeated Measures with Bonferroni correction comparisons over the three intervals for the two voice-related measures (VTD and VHI-9i) and for the two speech comprehension tests Spatial and Qualities of Hearing Scale (SSQ12 and monosyllables) were conducted. T-tests for vocal hygiene aspects and gender were performed for group comparisons. Further, the relation between voice-related measures and speech comprehension tests was assessed with Pearson's correlation coefficient.

Results: VTD Scale and VHI-9i results were on average under the cut-off score (14 % on average above cut-off in VTD Scale and 7.6 % in VHI-9i) and did not change significantly over time (VTD Scale mean = 11.57, SD = 12.37 at FF and mean = 11, SD = 12.6 at 12 months, VHI-9i mean 5.87, SD = 5.733 at FF and mean = 6.14, SD = 5.93 at 12 months). The number of correct monosyllables (mean = 57.5, SD = 22.8 to 67.1, SD = 22) and SSQ12 scores (mean = 3.5, SD = 1.9 to mean = 4.4, SD = 1.9) improved significantly within the first year of CI use. Gender had an impact on VTD Scale and VHI-9i scores: women scored significantly higher than men. There was a weak correlation for VTD Scale at FF ($r = -.220$, $p < .05$) and 3M ($r = -.263$, $p < .05$). and for VHI-9i at 3M ($r = -.39$, $p < .001$) and 12M ($r = -.285$, $p < .001$). In the group of non-vocal professionals, the difference in VTD Scale score from FF to 12M was significant ($p = .021$), with the mean decreasing from 11.29 (SD = 13.46) points to 7.53 (SD = 11.9). VHI-9i scores stayed the same over all three time points in this group.

Conclusion: In the present study of adult CI users up to 82 years, there were no subjective voice symptoms although speech comprehension did change significantly. Thus, the assumption, that people with CI more often suffer from a voice disorder could not be proved by this study.

Abstrakt

Zielsetzung: Hörbeeinträchtigungen können zu Veränderungen der Stimmgebung und Artikulation führen. Bisherige Studien zeigen jedoch, dass dies auch eine Stimmstörung zur Folge haben kann. Die durch ein Cochlea Implantat (CI) hervorgerufene Veränderung des Hörvermögens ist gut belegt, die Auswirkungen auf die Stimme aus PatientInnen-sicht wurden hingegen selten untersucht. Daher war das Hauptziel dieser Studie, die subjektive Stimmbeeinträchtigung und Beschwerden im Vokaltrakt bei CI TrägerInnen sowie deren Zusammenhang mit der Verbesserung des Sprachverständnisses im ersten Jahr der CI Nutzung zu untersuchen. Darüber hinaus wurde der Einfluss von Geschlecht, Stimmhygiene, Stimmgebrauch und Stimmtherapie analysiert.

Studiendesign: Prospektive Längsschnittstudie.

Methode: 83 Erwachsene (43 Frauen und 40 Männer) im Alter von 24 bis 82 Jahren, die ein CI erhielten, wurden zum Zeitpunkt der Erstanpassung (FF), nach 3 Monaten und nach 12 Monaten untersucht. Stimmbezogene subjektive Symptome wurden mithilfe der Vocal Tract Discomfort Scale (VTD), des international validierten Voice Handicap Index (VHI-9i) und eines eigens entwickelten Fragebogens zur Erfassung von Stimmgebrauch und -hygiene, vorangegangener Therapie und anderen Einflussfaktoren, wie z. B. dem Geschlecht, erfasst. Das Sprachverständnis mit dem CI wurde mit dem Freiburger Sprachtest (FBE) anhand von Einsilbern in ruhiger Umgebung untersucht. Die subjektive Hörfähigkeit wurde mit dem Fragebogen „Speech, Spatial and Qualities of Hearing Scale“ (SSQ-12) erfasst. Es wurden deskriptive Statistiken sowie eine einfaktorielle Varianzanalyse (ANOVA) mit Messwiederholung und Bonferroni-Korrektur für die drei Messintervalle der beiden stimmbezogenen Messgrößen (VTD und VHI-9i) und der beiden Sprachtests (SSQ-12 und FBE), sowie T-Tests für Gruppenvergleiche für die Faktoren Stimmhygiene und Geschlecht durchgeführt. Des Weiteren wurde der Zusammenhang zwischen stimmbezogenen Messwerten und Sprachtests mittels Pearson-Korrelationskoeffizient untersucht.

Ergebnisse: Die Ergebnisse der VTD Skala und des VHI-9i lagen im Durchschnitt unter dem Cut-Off Wert (durchschnittlich 14 % über dem Cut-Off bei der VTD Skala und 7,6 % beim VHI-9i) und veränderten sich im Zeitverlauf nicht signifikant (VTD Skala: MW = 11,57, SD = 12,37 bei FF und MW = 11, SD = 12,6 nach 12 Monaten; VHI-9i: MW = 5,87, SD = 5,733 bei FF und MW = 6,14, SD = 5,93 nach 12 Monaten). Die Anzahl korrekt nachgesprochener einsilbiger Wörter (MW = 57,5, SD = 22,8 bis 67,1, SD = 22) und die SSQ12-Werte (MW = 3,5, SD = 1,9 bis MW = 4,4, SD = 1,9) verbesserten sich im ersten Jahr der CI Nutzung signifikant. Das Geschlecht hatte einen Einfluss auf die Ergebnisse von VTD Skala- und VHI-9i: Frauen erzielten signifikant höhere Werte als Männer. Es zeigte sich eine schwache Korrelation für die VTD Skala zum Zeitpunkt der Implantation ($r = -0,220$, $p < 0,05$) und nach 3 Monaten ($r = -0,263$, $p < 0,05$) sowie für den VHI-9i zum Zeitpunkt nach 3 Monaten ($r = -0,39$, $p < 0,001$) und 12 Monaten ($r = -0,285$, $p < 0,001$). In der Gruppe der nicht-sprechenden Berufstätigen war der Unterschied im Score der VTD Skala zwischen FF und 12M signifikant ($p = 0,021$), wobei der MW von 11,29 (SD = 13,46) Punkten auf 7,53 (SD = 11,9) sank. Die VHI-9i-Werte blieben in dieser Gruppe über alle drei Messzeitpunkte hinweg unverändert.

Schlussfolgerung: In der vorliegenden Studie mit erwachsenen CI TrägerInnen bis zu 82 Jahren traten keine subjektiven Stimmbeschwerden auf, obwohl sich das Sprachverständnis signifikant veränderte. Die Annahme, dass Menschen mit CI häufiger an einer Stimmstörung leiden, konnte daher durch diese Studie nicht bestätigt werden.

Keywords:

Hearing Impairment, Cochlear Implantat, Self-Perception of Voice, Vocal Tract Discomfort Scale, Voice Handicap Index

Schlüsselwörter

Hörschädigung, Cochlea Implant, stimmliche Selbsteinschätzung, Vocal Tract Discomfort Scale, Voice Handicap Index

INTRODUCTION

The human voice is not only a primary means of communication - it is also a core aspect of our identity (Zarate, 2013). Through our voice, we convey emotions, intentions, and personality traits. Central to our ability to control vocal attributes such as pitch, loudness, and prosody are the auditory feedback loop: we perceive our own voice via both air and bone conduction. This self-perception enables dynamic adjustment and fine motor control of the voice during speech.

In individuals with hearing impairment, this feedback loop is disrupted and changes in hearing can interfere with respiration, articulation, and phonation (Selleck & Sataloff, 2014; Tourville et al., 2008). Gautam et al. (2019) showed in a systematic literature review that hearing loss has a measurable impact on vocal function, particularly on parameters such as fundamental frequency (F0), sound pressure level (SPL), jitter, shimmer, and voice onset time. These voice alterations are not merely technical, they can have profound effects on communication behavior, psychosocial well-being, and self-concept (Gautam et al., 2019).

Hengen et al. (2018) conducted a study using the VHI-9i to assess differences in perceived voice problems between individuals with normal hearing, those with hearing impairment who did not use a hearing aid, and those who did. The results showed significantly higher scores in both groups with hearing impairment, indicating a greater perceived voice handicap in daily life. Acoustic measurements, however, were not significantly different. In another study on hearing-impaired Hengen et al. (2020) found that the primary reason for poor perceived sound quality of one's own voice is the use of a hearing aid. While hearing aids are used in persons with mild to moderate hearing impairment, cochlear implants (CI) offer people with severe to profound hearing loss the opportunity to regain access to auditory information through electrical stimulation. CIs enable significant gains in speech comprehension, but the nature of auditory input via a CI differs substantially from natural hearing. Consequently, CI users often experience their voice as changed - foreign, mechanical, or overly loud. These perceptions can interfere with vocal control, fluency, and emotional expression. Especially for women, who are often more attuned to vocal aesthetics due to social conditioning, such

shifts can pose particular challenges (Hengen et al., 2018). A recent study showed that CI users have mild to moderate dysphonia when turning on their CI, this was measured using the acoustic parameters Acoustic Voice Quality Index (AVQI) and smoothed Cepstral-Peak Prominence (CPPS) (Guastamacchia et al., 2024).

In a previous cross-sectional study (Lukaschyk & Illg, 2022), voice-related self-perception was assessed in 124 CI users shortly after first fitting. Contrary to expectations, the participants reported low levels of discomfort and self-perceived voice handicap, as measured by the German versions of the Vocal Tract Discomfort (VTD) Scale and the Voice Handicap Index 9 international (VHI-9i). Interestingly, no significant correlation was found between these self-assessment scores and speech comprehension, residual hearing, type of treatment, or age. This finding challenges the assumption that improved auditory input automatically leads to less voice-related subjective symptoms.

Although voice production is rarely the focus in CI research, studies like the systematic review by Ashjaei et al. (2024), including 75 studies on vocal control and speech production in CI users, suggest that many CI users achieve speech quality comparable to normal - hearing individuals, however, some features still deviate in a group of CI users even years post-implantation, e.g., increased vocal jitter and shimmer, shorter voice onset time and limited prosodic patterns. These findings contribute to the assumption that auditory feedback plays a central role in modulating not only pitch and loudness but also fine motor aspects of speech. Gautam et al. (2019) showed that long-term CI users gradually improve voice pitch and volume regulation, but short-term control over prosodic features remains inconsistent. Historical studies from the 1980s and 1990s already noted this dissociation, and their findings were recently confirmed in new cohorts (Yuksel & Gunduz, 2019), including prelingually deaf CI users.

So far, clinical practice and research have concentrated primarily on objective outcome measures, such as hearing thresholds, word recognition scores, or measurable acoustic voice changes. Subjective symptoms such as vocal discomfort or self-perceived handicap have received significantly less attention, but are of high relevance for daily voice use. Moreover, these aspects are essential for a comprehensive understanding of rehabilitation needs. International recommendations, including those by the European Laryngological Society (Lechien et al., 2023) and the American Speech-Language-Hearing Association (Patel et al., 2018), emphasize the need for multidimensional assessment protocols to tailor

patient-specific treatment. These include five key domains: visual (e.g., laryngoscopy), aerodynamic (e.g., phonation time), acoustic (e.g., jitter, shimmer, Harmonics-to-Noise Ratio and Voice Range Profile), auditory-perceptual (e.g., the GRBAS (Grade, Roughness, Breathiness, Asthenia, Strain) scale), and self-assessment of subjective (e.g., VHI, VTD Scale) voice-related symptoms.

The VHI-9i, the internationally recognized short form with 9 questions of the original Voice Handicap Index, measures perceived limitations in everyday life caused by voice problems. It includes three subscales (functional, physical, emotional) and the total score ranges from 0 (no handicap) to 36 (severe handicap). The German VTD Scale, validated and cross-validated by Lukaschyk et al. (2017, 2021), adds valuable information by quantifying sensations of discomfort in the vocal tract, like dryness, tickling, or a lump in the throat. In the latest German guidelines for dysphonia diagnostics (DGPP, 2022), the combined use of VHI-9i and VTD is recommended to capture both functional limitations and subjective sensations.

Epidemiological data confirm the importance of addressing voice-related symptoms, particularly in women. The prevalence of voice disorders in the general US population lies between 3% and 9%, with women being 1.5 times more frequently affected (Roy et al., 2005). Factors contributing to this higher prevalence include greater social and professional demands on vocal expressiveness and aesthetic, increased susceptibility to vocal tract discomfort (Mathieson et al., 2009), and a higher likelihood of seeking medical attention (Hunter et al., 2011). Also, women with and without a voice disorder, as well as hearing-impaired women have been shown to consistently report more severe vocal complaints on both the VHI-9i and VTD scales (Lukaschyk et al., 2021; Lukaschyk & Illg, 2022).

Roy et al. (2005) identified reflux, chemical exposure, and high vocal load as further risk factors. A high vocal load is often related to one's profession. The vocal usage classification by Koufman (1991) distinguishes four levels of vocal demand by profession. For example, actors and singers (Level 1) rely fundamentally on their voice, followed by high-demand users like teachers (Level 2). Any impairment in voice quality in these groups can have serious occupational consequences, including absenteeism and psychological stress (Van Houtte et al., 2010).

Study Aims

Therefore, the main aim of the present study was to investigate changes in subjective voice related

handicap and vocal tract discomfort in adults within the first year of CI use as indicated by the VHI-9i and the VTD Scale. Moreover, it will be examined whether subjective voice perception is related to improved auditory input. For this purpose, the following questions are posed:

- How does the perception of voice-related symptoms and discomfort in the vocal tract change within the first year of CI use?
- Does gender influence subjective voice-related symptoms in CI users?
- Do vocal hygiene, voice usage and voice therapy influence the perception of voice-related symptoms in CI users?
- Is there a correlation between improvement in speech comprehension and voice-related self-perception in CI users?

MATERIALS AND METHODS

In a longitudinal study with 83 participants, of these 43 women and 40 men who underwent CI surgery, self-perception of voice was measured within the first year of CI usage at three time points.

Participants were volunteers who were implanted with a unilateral CI between October 2020 and December 2022 at the Clinic of Otorhinolaryngology at the Medical University of Hannover, Germany. All participants were investigated at three time points: first-fitting (FF), as well as 3 and 12 months after FF.

The responsible Ethics Commission of Hannover Medical School approved the study under reference number 9353_BO_A_2020.

Inclusion and Exclusion Criteria

Every patient who, in the given time range, was 18 years or older, spoke and read German fluently, received their first or second CI, participated as volunteer and gave informed consent was included. To enable the study to represent a wide range of different patient types, all participants were included regardless of the etiology of hearing loss or hearing status. Also, patients were included regardless of whether they had received voice therapy prior to implantation.

Participant Characteristics

The study group consisted of 83 participants (43 female and 40 male) between 24 and 82 years old (mean age of 53.93, SD = 14.28), who were allocated according to vocal usage to 4 Levels Koufman (1991): 19 were professional voice users (Level 1),

43 non-vocal professionals (Level 2) and 21 non-vocal non-professionals (Level 4), with different treatment statuses, e.g., bilateral CI users, unilateral CI recipients with bilateral deafness, unilateral CI users with single-sided deafness, different etiologies, and different progressions of hearing loss. Participants had a mean duration of hearing loss of 25.7 years (SD = 19.69, min-max = 0.5–78) and duration of deafness of 14.0 years (SD = 16.64, min-max = 0–53). Please refer to Table. 1 for detailed information concerning treatment and etiology and Table. 2 for the CIs used in the study population.

Assessment of Voice and Hearing

Usually, at 4 to 6 weeks after CI surgery, patients return to the clinic for CI activation and to receive the first rehabilitation. This is called the first-fitting (FF) and was our first measurement time point.

To assess self-perception of voice-related symptoms, all participants filled in the German versions of the VTD Scale and the VHI-9i, plus a specifically

[n=83]	
Kind of treatment	
Bimodal (CI & HA)	39
Bilateral CI	22
Unilateral CI, SSD	20
Unilateral CI, contralateral residual hearing	1
Unilateral CI, contralateral deafness	1
Time of deafness	
Prelingual	7
Perilingual	5
Postlingual	71
Etiology	
Unknown	48
Sudden hearing loss	17
Menière's disease	3
Genetic	4
Other	11
Progress of hearing loss	
Progressive	44
Acute	17
Since childhood	9
Unknown	13
Implantation Quantity	
First	68
Reimplant	14
Re-Reimplant	1

Table 1. Participant characteristics of Hearing Impairment, Treatment Status and additional anamnestic Data

Manufacturer (Implant Type)	Left side	Right side
Advanced Bionics (HiRes Ultra HiFokus SlimJ, HiRes Ultra 3D Hi- Fokus Mid-Scala, HiRes Ultra 3D HiFokus SlimJ, HiRes 90K Advantage HiFokus Mid-Scala)	15	10
Cochlear (Nucleus CI 422, Nucleus 512 Profil (CA), Nucleus CI 522, Nucleus CI 612, Nucleus CI 622, Nucleus CI 624, Nucleus CI 632)	19	21
MED-EL (Synchrony Flex 28, Synchrony 2 Flex 28, Synchrony2 Flex 28 S-Vector, Synchrony2 Flex Soft)	20	13
Oticon (Oticon Neuro ZTI EVO)	4	3

Table 2. Distribution of manufacturers on both ears

developed German questionnaire to evaluate inclusion and exclusion criteria.

The VTD Scale consists of two subscales, which assess the severity and frequency of eight symptoms (burning, tight, dry, pain, sore, tickling, irritated, and lump in the throat). Each item is rated on a 7-point Likert-scale from 0 to 6. A total score is calculated by adding up all the scores. Thus, the possible total scores can run between 0 and 48 points. Cut-off scores are the ranges: no (score: 0-13), mild (score: 14-26), moderate (score: 27-40), and severe (score: 41-48) disorder (Lukaschik et al., 2021).

With the short form comprising 9 questions, the VHI-9i, the impact of a voice disorder on daily life is assessed with three subscales: functional, physical, and emotional. Each item is rated on a 5-point Likert scale from 0 to 4, resulting in a maximum total score of 36. Severity levels are classified as follows: 0–7 = no impairment, 8–16 = mild, 17–26 = moderate, and 27–36 = severe impairment.

To assess inclusion and exclusion criteria, a specific questionnaire with 17 items regarding vocal hygiene-related habits like alcohol use, smoking, hearing history, voice therapy, voice related diagnosis (if applicable), hormone intake, and allergies, as well as voice usage in hours per day and the question whether the participant did receive or is receiving voice therapy.

Hearing assessment consisted of the objective testing of monosyllables using the Freiburger Speech Intelligibility Test (FBM) (Hahlbrock, 1953). The signal was played from the front at 65 dB SPL (SON0). If residual hearing was present on the contralateral side, a masking sound, a voice-simulating noise of the International Telecommunication Union (Comité Consultatif International Téléphonique et Télégraphique, CCITT), was presented via headphones on the contralateral side. The loudness

of the masking noise was calculated according to the general audiometric rules (Lehnhardt, 2009). Masked audiometry is an internationally recognized audiometric procedure used when audiometry or speech audiometry is measured on asymmetrically hearing ears, as sound is heard from the normal-hearing ear to the impaired ear through bone conduction. The volume of the masking noise in a speech audiogram administered to the normal-hearing ear is then 60-70 dB above normal air conduction thresholds. Participants assessed their subjective hearing abilities via the Speech, Spatial and Qualities of Hearing Scale (SSQ12) questionnaire, which is one of the most commonly used instruments to assess the effects of hearing aid or cochlear implant fitting (Gatehouse & Noble, 2004; Moulin et al., 2019). The SSQ12 provides information about everyday hearing abilities. Twelve questions are scored from 0 to 10 points. Subscale and total scores are calculated by averaging the subscale scores. Higher scores indicate less difficulty or no difficulty at all. Both the FBM and SSQ12 allow the capture of treatment benefits and real-world experiences for CI recipients.

Statistical analysis

Statistical analysis was performed using SPSS statistical software (IBM, 2021). Descriptive statistics were conducted for treatment status (use of devices, e.g. unilateral or bilateral CI, bimodal use of CI and hearing aid) and medical history data, like severity and duration of hearing impairment, modality of hearing, and the self-perception of voice, and were presented as number, mean and standard deviation (SD), minimum (min), and maximum (max). For inferential statistics, the level of significance was set to $p = .05$.

One-Way Analysis of Variance (ANOVA) for Repeated Measures with Bonferroni correction was conducted for comparisons over the three intervals for the two voice-related measures (VTD Scale and VHI-9i), subgroups of voice usage level, gender, and for the two speech comprehension tests (SSQ12 and monosyllables).

A normal distribution was assumed due to the sample size $n > 30$ (Universität Zürich, 2023).

T-tests for different subgroups of vocal hygiene aspects like voice usage level, smoking, speech comprehension (SSQ12 and monosyllables) and voice symptoms (VTD Scale and VHI-9i) were performed.

Correlations between the VTD Scale and VHI-9i with Speech Comprehension Measured by Monosyllables and SSQ12 were evaluated using Pearson's correlation coefficient.

RESULTS

Voice-related Self-perception Measured by VTD Scale and VHI-9i

Values for VTD Scale varied between mean = 11.57 and 9.22, with the lowest scores at 3M (Table 3). Subscales of frequency and severity differed at FF and 12M and were nearly identical at 3M.

The VHI-9i total scores varied between 5.87 and 6.14, with the highest scores at 12M and lowest at 3M. For the subscales of the VHI-9i (functional, physical, and emotional) the highest scores were found in the *functional* subscale in all three intervals. The lowest scores were found in the emotional subscale at all three timepoints (Table 4).

There were no significant changes between the three intervals for the VTD Scale ($F(1.837) = 1.893$, $p = .159$) or the VHI-9i ($F(1.803) = .910$, $p = .396$). Allocating the mean scores for both questionnaires to one of the 4 ranges of degrees of handicap or

discomfort, both were on average in the range of no handicap/discomfort (Figure 1).

The most common symptoms were “dry”, “irritated” and “lump in the throat” at FF. At 3M and 12M “tight” was also frequently reported.

The distribution according to the severity ranges of the VTD Scale (Lukaschyk et al., 2021) and the VHI-9i (Caffier et al., 2021) can be found in Table 5. At FF, $n = 11$ scored above the cut-off score on the VTD Scale; at 3M, the lowest number was observed with $n = 8$ persons above the pathological cut-off, and at 12M the highest number was found with $n = 13$.

Similarly, for the VHI-9i, the lowest number, with $n = 4$, was at the interval 3M, $n = 6$ at FF, and the highest proportion of 10% ($n = 8$) at 12M.

Gender-related Characteristics

Mean scores in VTD Scale and VHI-9i over all intervals were higher in female participants compared to male participants. Significant differences between men and women could be found at FF in both voice-relating self-rating tools VTD Scale ($F(1) = 7.68$, $p = .007$) and VHI-9i ($F(1) = 5.65$, $p = .020$) as well as in VHI-9i at 3M ($F(1) = 4.11$, $p = .047$). Women had significantly higher scores at these intervals (see Figure 2), however not at 12M. For detailed scores for both gender see supplementary material Table 1.

Vocal Hygiene, Voice Usage and Voice Therapy

Ten participants (12 %) reported that they were currently receiving voice therapy. Two of these had a structural voice disorder. Comparing the subgroup of participants receiving voice therapy to the rest, there were no significant differences. However, there was a trend towards higher scores in both voice-related questionnaires VTD Scale and VHI-9i for those receiving voice therapy. For explicit values of mean and SD,

	VTD FF	VTD 3M	VTD 12M
Mean	11.57	9.22	11.0
Median	6	6	7
SD	12.37	11.3	12.6
Min.	0	0	0
Max.	41	46	41

	VTD F	VTD S	VTD F	VTD S	VTD F	VTD S
Mean	5.06	5.79	4.68	4.69	4.66	5.11
Median	2.0	3.0	3.0	2.0	2.0	2.0
SD	5.92	6.57	5.41	5.85	6.16	6.89
Min.	0	0	0	0	0	0
Max.	23	28	22	24	26	28

Table 3. Descriptive Data of VTD Scale total Score and Subscales for all three intervals

	VHI FF	VHI 3M	VHI 12M
Mean	5.87	5.38	6.14
Median	4	4	5
SD	5.73	5.35	5.93
Min.	0	0	0
Max.	24	23	25

	VHI F	VHI P	VHI E	VHI F	VHI P	VHI E	VHI F	VHI P	VHI E
Mean	2.85	2.75	.69	2.62	2.24	.70	2.81	2.75	.71
Median	2	2.50	0	2	2	0	2	2	0
SD	3.21	2.63	1.59	2.59	2.51	1.3	3.20	2.79	1.54
Min.	0		0	0	0	0	0	0	0
Max.	13	10	8	10	11	7	13	11	8

Table 4. Descriptive Data of VHI-9i total Score and Subscales for all three intervals

Degree of Discomfort/Handicap	VTD Scale Score	FF No. (%) of 81	3M No. (%) of 65	12M No. (%) of 83	VHI-9i Score	FF No. (%) of 80	3M No. (%) of 65	12M No. (%) of 82
no	0-13	51 (63)	46 (71)	58 (70)	0-7	55 (69)	46 (71)	52 (63)
mild	14-26	19 (23)	11 (17)	12 (14)	8-16	19 (24)	15 (23)	22 (27)
moderate	27-40	10 (13)	7 (11)	10 (12)	17-26	5 (6)	4 (6)	7 (9)
severe	41-96	1 (1)	1 (1)	3 (4)	27-36	1 (1)	0 (0)	1 (1)

Table 5. Distribution of severity ranges of VTD Scale and VHI-9i for all three time points

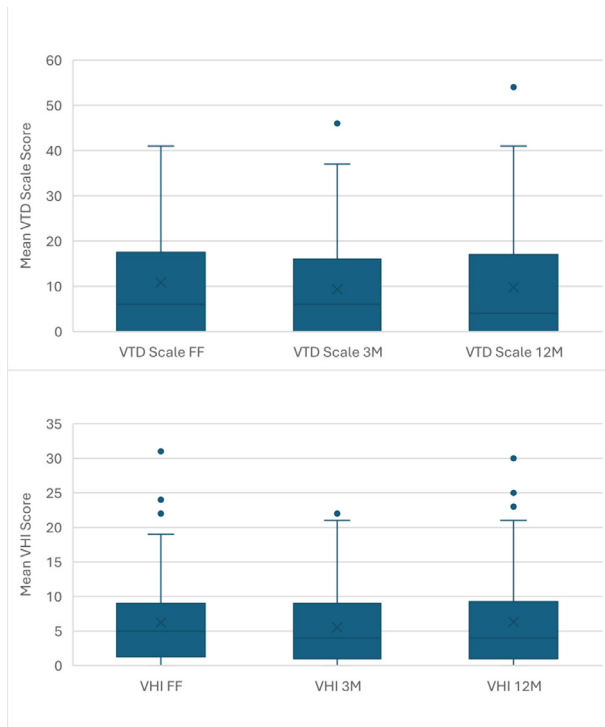


Figure 1. Boxplots for VTD Scale and VHI-9i over 3 intervals.

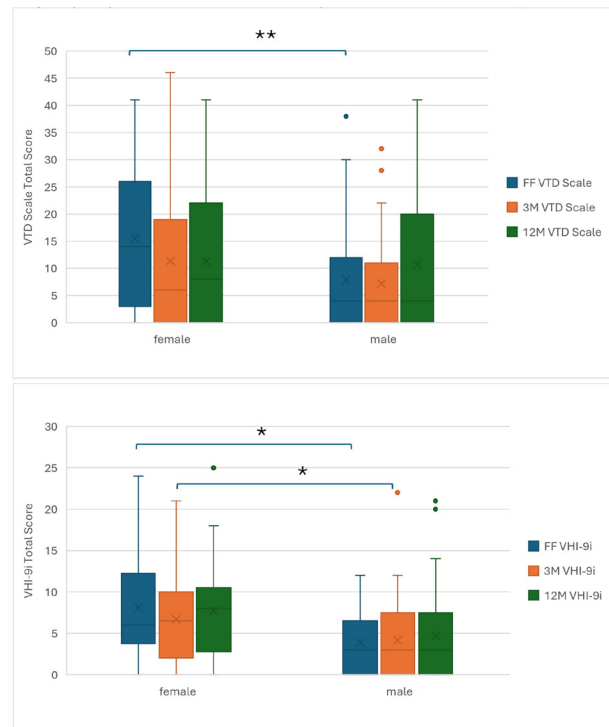


Figure 2. Box Plot of male and female in VTD Scale and VHI-9i over all three time points.

see supplementary material (Table 2). Boxplots of these group comparisons are presented in Figure 3. Participants self-reported vocal usage was on average 8.3 hours per day. 42 participants (50%) declared themselves to be non-smokers, 26 (31%) used to smoke but had quit, and 15 (18%) were active smokers. When comparing these three subgroups, we found no differences in VTD Scale scores. The intake of hormones was stated by $n = 10$ female participants. Alcohol use was indicated by $n = 64$, 18 persons reported no alcohol consumption, and 1 person did not answer this question. Following Koufman (1991) participants were distributed to 4 different levels of voice professionals. The sample did not include anyone in Level 1. 19 persons were allocated to Level 2 (professional voice-users) (22.9 %). The largest group was Level 3: non-professional voice-users with $n = 43$ persons (51.8 %). About a quarter of the sample with 21 persons (25.9 %) were persons with a profession without voice usage.

In the group of non-professional voice users (Level 3), the difference in VTD Scale score from FF to 12M was significant ($t(40) = 2.096$, $p = .021$), with the mean decreasing from 11.29 (SD = 13.46) points to 7.53 (SD = 11.9). VHI-9i scores stayed the same over all three time points in this group.

There were no significant differences when comparing Level 3 and 4 to Level 2 ($p = .20-.49$).

Levels 2 and 4 showed the same decrease in VTD and VHI-9i scores as the total group at time point 3M. In-depth info on scores can be found in the supplementary material (Sup., Table 3 and 4).

Speech Comprehension Measured by Monosyllables and SSQ12

See Figure 4 for boxplots of monosyllables and SSQ12 total score for all three intervals and Table 6 for the values of both.

For monosyllables, significant differences were found ($F(61) = 5.35$, $p = .007$) with an increase in performance across intervals. Changes were significant between FF and 3M ($p = .046$) and between FF and 12M ($p = .008$). Changes from 3M to 12M were not significant ($p = .52$).

For the SSQ12 total score, significant differences were found ($F(1.836) = 15.003$, $p < .001$) with an increase in score across intervals. Changes were significant between the scores at FF and at 3M ($p < .05$) as well as between FF and 12M ($p < .05$). Changes from 3M to 12M were not significant ($p = 1.0$).

Correlation between Hearing Performance and Voice Symptoms

There was a weak but statistically significant correlations between the speech comprehension tests

($r = .287-.319$, $p < .05$). For monosyllables and VTD Scale, there was also a weak and statistically significant negative correlation at FF and 3M ($r = -.220$, $r = -.263$, $p < .05$) as well as monosyllables and VHI-9i at 3M and 12M ($r = -.391$, $r = -.285$, $p < .001$).

The correlation between VTD and VHI-9i was positive and statistically significant, with weak and moderate values over all three time points ($r = .339-.699$, $p < .05$).

DISCUSSION

Results showed that voice-related self-perception scores did not change significantly within the first year of CI usage. Whereas speech comprehension and subjective hearing abilities improved significantly within this time range. Gender showed a significant impact on VTD Scale and VHI-9i scores with higher

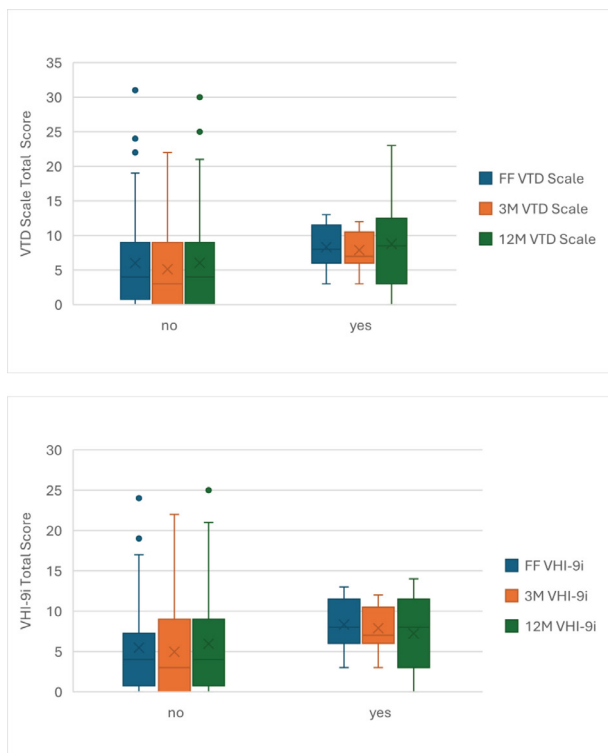


Figure 3. VTD Scale and VHI-9i in recipients and non-recipients of voice therapy.

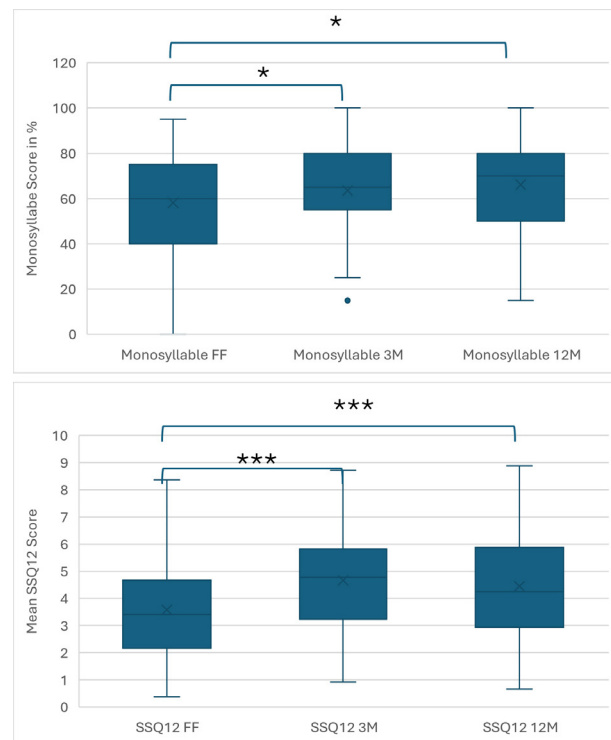


Figure 4. Boxplots of monosyllables and SSG12 total score for all three intervals.

	Mono-syllables FF	Mono-syllables 3M	Mono-syllables 12M	SSQ12 FF	SSQ12 3M	SSQ12 12M
Mean	57.54	63.31	67.12	3.58	4.66	4.44
SD	22.84	19.29	22.03	1.94	1.91	1.92
Min.	0	15	15	.38	.92	.67
Max	95	100	100	8.37	8.72	8.88

Table 6. Descriptive Data on Monosyllables and SSQ12 for all three intervals

scores in women. There was a weak correlation between speech comprehension and voice-related self-perception.

Voice-related Self-perception and Hearing Impairment

No significant changes were found across all time points for VTD Scale and VHI-9i scores. This might be because a CI is not an intervention addressing voice problems, and there was no offer of any intervention concerning improvement of voice quality. Nonetheless, ten participants underwent voice therapy during the course of the longitudinal study. Literature, however, suggests an improvement – and therefore a correlation – in hearing, which can lead to better voice control according to improved auditory feedback (Selleck & Sataloff, 2014; Tourville et al., 2008; Ubrig et al., 2011).

Another reason for no significant changes could be that very few participants scored above the cut-off score ($n = 14$ at FF and $n = 16$ at 12M out of 83 participants in total) and had therefore no indicator for a voice disorder, and little range for positive change. One reason for these low scores on both self-perception questionnaires could be a lack of self-awareness towards voice. Another could be that the participants' likely focus with their CI was improving (or enabling) speech comprehension, not the quality of their voice. A third reason could be that most participants were postlingual adults, who did not have a problem with their voice in the first place.

The VTD severity subscale showed higher scores than the subscale frequency. This is an argument for keeping both subscales and not just using one scale as Stappenbeck et al. (2019) suggested.

As expected, and documented in other studies (e.g., (Buchner et al., 2017; Heuninck et al., 2023; Illg et al., 2022)), significant improvements in monosyllabic comprehension can be measured already after 3 months of CI use. After 3 months, further increase in speech understanding is not very steep. Subjective hearing ability reflects the same development: there is no correlation between the voice-related self-perception and monosyllables or SSQ12 data. As suggested, both measures should be considered separately.

The initial hypothesis when first applying the VTD Scale in CI users (Lukaschik & Illg, 2022) was that voice problems would be more prevalent in CI users than in the general population. This hypothesis was rejected. It seems reasonable to assume that the group of hearing-impaired individuals with a CI is not particularly susceptible to classic voice disorders.

However, years of auditory impairment could have caused functional losses in the fine-tuning of the vocal folds, which could be reversible with more input from the CI. The objective was to identify an uncomplicated initial method for the detection of such symptoms. Given that the VTD and VHI are considered the gold standard in phoniatrics and are straightforward to administer as self-assessment questionnaires, this survey was selected. This should not preclude an organic examination of the vocal folds.

If a result is above cut-off, further assessment of the voice should be conducted to determine if a therapeutic intervention is needed. The findings of this study indicate that the utilization of a CI for a 12-month period does not result in an improvement in vocal symptoms or a modification of the initial state of the voice. The study suggests that the prognosis for voice disorders is independent of hearing status and therefore comparable to that of normally hearing individuals. In contrast changes in prosody and articulation are associated with deafness or severe hearing impairment, as Hawthorne (2024) showed in a recent meta-analysis.

Vocal Hygiene, vocal usage and the VTD Scale

The proportion of people who smoke in Germany is around 19% (16.2 Mio.; Statista, 2015), which is well represented in our sample. A study done by Tohidast et al. (2023) found significant differences between a smoking and non-smoking group in vocal tract discomfort measured by the VTD Scale. When comparing the three subgroups of active smokers, those who had quit, and non-smokers in the sample, no differences were found in VTD Scale scores. Looking at the items, the three most reported symptoms (dry, irritated, lump in the throat) were the same as in a study by Nawaz et al. (2022), who assessed only persons with voice disorder. Looking at the symptoms most reported by smokers, the hierarchy was: irritation, sore, tickling, burning, tight, lump in the throat, dry, and aching symptoms. Thus, there seems to be a difference between smokers and non-smokers which could not be replicated in the present study, although it should be considered that the study sample by Tohidast et al. (2023) was only male.

Interestingly, in the group of non-professional voice users (Level 3 according to Koufman (1991)) the difference in VTD Scale score from FF to 12M was significant. This was the only subgroup where a significant change with better results after 12 months could be detected. Non-professional voice users seem to gain the highest vocal benefit from CI use.

Gender Characteristics

In the present study, the gender distribution was equal. This is noteworthy because in most voice-related studies the proportion of women to men is around 2:1, a fact which complicates inter-gender comparison (e.g. Cantor Cutiva et al., 2013). Also in this sample, women have higher scores than men on both VTD Scale and the VHI-9i. This may be due to higher vulnerability of the female larynx and the higher sensitivity to discomfort and pain compared to men (Bartley & Fillingim, 2013; Hunter et al., 2011; Lechien et al., 2022). The gendered difference in results suggests that either women suffer more voice problems than men or are more likely to give higher scores on self-rating instruments. This is important to consider in therapy and counselling.

Strengths and Limitations

A strength of this study is that it is, to the best of our knowledge, the first longitudinal assessment focusing on CI users' voice-related self-perception during their first year after device provision. A limitation is the composition of the study group: all CI recipients regardless of their hearing ability in the contralateral ear or type of CI they received were included.

Only 1 of the 5 domains of the Basic Protocol by the Europe Laryngeal Society was addressed, namely the self-perception of voice. As a result, no final statement can be made as to whether the participants had a voice disorder or not. The use of validated questionnaires can only be seen as an

indicator of further investigation when comparing to normative data.

Conclusion and Future Perspectives

The use of a CI does not affect how users perceive the quality or characteristics of their own voice. The VTD Scale and the VHI-9i have proven to be practical and effective instruments for CI users to evaluate their own voice, providing valuable insights for screening potential voice disorders. As expected, users experienced notable improvements in both speech comprehension and their perceived hearing abilities throughout the first year following the implantation of the CI.

In future perspective it would be interesting to conduct a study with other domains of the Basic Protocol by the European Laryngeal Society in postlingually deafened patients with CI.

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Financial Disclosures / Conflicts of Interest

The authors declare that the second author is employee of the company MED-EL.

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SUPPLEMENTARY MATERIAL

		N	Mean	SD	Min.	Max.
FF VTD	female	41	14.36	13.25	.00	41.00
	male	40	7.25	9.48	.00	38.00
3M VTD	female	32	11.50	12.84	.00	46.00
	male	33	7.21	9.15	.00	32.00
12M VTD	female	43	10.62	13.31	.00	54.00
	male	40	8.85	12.59	.00	41.00
FF VHI-9i	female	40	7.87	7.32	.00	31.00
	male	40	4.57	4.82	.00	22.00
3M VHI-9i	female	32	6.87	5.60	.00	21.00
	male	33	4.18	5.08	.00	22.00
12M VHI-9i	female	42	7.47	6.45	.00	25.00
	male	40	5.10	6.70	.00	30.00

Sup Table 1. Scores of VTD Scale and VHI-9i according to gender

	Voice Therapy	No.	Mean	SD
FF VTD	no	71	10.1127	11.49105
	yes	9	17.5556	15.04253
3M VTD	no	55	8.8727	11.39859
	yes	9	12.6667	10.85127
12M VTD	no	72	9.1944	12.90228
	yes	10	14.5000	13.31040
ff VHI-9i	no	70	6.0143	6.67570
	yes	9	8.3333	3.24037
3M VHI-9i	no	56	5.1250	5.70825
	yes	9	7.8889	2.93447
12M VHI-9i	no	71	6.0423	6.63634
	yes	10	8.8000	6.69660

Sup Table 2. Group comparison of voice therapy recipients and non-recipients

		FF VTD	3M VTD	12M VTD	FF VHI-9i	3M VHI-9i	12M VHI-9i	FF SSQ12	3M SSQ12	12M SSQ12
N	Valid	25	18	19	24	17	19	24	19	20
	Missing	0	7	6	1	8	6	1	6	5
Mean		9.7200	8.4444	11.7368	5.9167	5.2353	6.3684	44.1375	52.7842	50.1500
Median		6.0000	5.5000	4.0000	4.5000	6.0000	6.0000	44.9000	46.5000	48.7500
Std. Deviation		10.94882	10.70031	14.86922	4.94242	4.93114	5.48949	25.79196	24.47796	24.09004
Minimum		.00	.00	.00	.00	.00	.00	7.30	16.00	12.00
Maximum		34.00	37.00	54.00	17.00	17.00	17.00	100.00	100.00	104.20
Percentiles	25	.5000	.0000	.0000	2.0000	.5000	1.0000	20.2500	33.0000	33.0500
	50	6.0000	5.5000	4.0000	4.5000	6.0000	6.0000	44.9000	46.5000	48.7500
	75	18.5000	13.2500	22.0000	9.7500	8.0000	10.0000	61.8750	71.0000	56.6000

Sup Table 3. VTD Scale, VHI-9i, SSQ12 over 3 time points in professsional voice users (Level 2)

		FF VTD	3M VTD	12M VTD	FF VHI-9i	3M VHI-9i	12M VHI-9i	FF SSQ12	3M SSQ12	12M SSQ12
N	Valid	60	43	43	61	45	43	63	44	43
	Missing	3	20	20	2	18	20	0	19	20
Mean		11.2000	10.5116	7.5814	6.4918	5.8222	6.6279	40.5952	55.3045	54.6512
Median		5.0000	6.0000	.0000	4.0000	3.0000	4.0000	35.8000	55.3500	50.0000
Std. Deviation		12.87594	13.27255	11.66034	7.08431	6.84002	7.61272	24.42461	24.61083	24.14584
Minimum		.00	.00	.00	.00	.00	.00	.00	19.00	8.00
Maximum		41.00	49.00	41.00	31.00	22.00	30.00	100.40	104.60	106.50
Percentiles	25	.0000	.0000	.0000	.0000	.0000	.0000	20.0000	35.0000	34.0000
	50	5.0000	6.0000	.0000	4.0000	3.0000	4.0000	35.8000	55.3500	50.0000
	75	17.7500	19.0000	10.0000	9.5000	9.5000	9.0000	50.0000	71.8750	75.9000

Sup Table 4. VTD Scale, VHI-9i, SSQ 12 over 3 time points in non-vocal professionals (Level 3)