COCHLEAR IMPLANTATION AS A TREATMENT OPTION FOR ADULTS WITH POST-LINGUAL SINGLE SIDED DEAFNESS: A SYSTEMATIC REVIEW OF THE LITERATURE

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INTRODUCTION

SINGLE-SIDED DEAFNESS- SSD is a term used to describe individuals with severe to profound hearing loss in one ear with a universal trend of having preserved or aidable audiometric thresholds in the unaffected ear. Sudden sensorineural hearing loss is the most common cause of SSD, though other etiologies are well documented including Meniere's disease, unilateral vestibular schwannoma, temporal bone fracture, labryinthitis, unilateral noise damage and ototoxic drug exposure (Giardina et al. 2014).

***BINAURAL HEARING*-** Binaural hearing has been demonstrated to be superior to unilateral hearing in regards to speech perception in noise and sound localization (Buss et al. 2008; Dubno et al. 2008).
Head-shadow effect- A phenomenon that occurs when the head obstructs sounds arriving from different locations. It allows the listener to always be able to utilize the ear with the more favorable SNR.
Binaural summation- Binaural summation causes an increase loudness of the signal. In addition, it allows for redundancies in the auditory signal which may result in greater frequency and intensity discrimination.
Binaural squelch effect- The advantage gained through the addition of the ear with the poorer SNR compared to listening monaurally with the better SNR ear alone. This allows for comparison of timing, amplitude and spectral differences in the signals arriving from each ear which provides a greater representation of the signal (Tyler et al., 2002).

SPEECH PERCEPTION IN NOISE*-** The benefits of binaural stimulation for speech comprehension are specifically attributed to the effects of ***binaural squelch and ***binaural summation***.

Binaural squelch- Allows for the brain to selectively filter noise from an incoming sound, particularly when noise and speech have different locations. This results in inter-aural differences in level, phase and timing that allow for the speech to be "unmasked" (Dirks & Wilson, 1969). Various studies reported advantages of binaural squelch in gains of 2-5 dB in SNRs for speech in noise.
Binaural summation- Phenomenon that results in an additive effect of perceived intensity of approximately 2-6 dB in SRT compared to a monaural listening condition (Giardina et al. 2014).
Head shadow effect- Can attenuate signals directed towards the affected ear anywhere from 10-16 dB by the time they reach the contralateral ear.

LOCALIZATION*-** Dependent upon accurate calculation of three spatial coordinates including ***azimuth, ***elevation***, and ***distance***. Directional hearing for determining the azimuth of a signal depends on binaural differences in sound arrival time and interaural level differences caused by the head shadow effect for higher frequencies. Monaural listeners lack these cues, as no interaural comparisons between sound level and timing can be made (Wanrooij & Opstal, 2007). Monaural cues for sound localization are limited to acoustic changes caused by the outer ear structures including the pinna and external auditory canal (Tokita et al. 2004). ***For monaural listening, acoustic cues derived from the modifications in the spectral composition of the signal are ineffective in aiding in horizontal localization*** (Giardina et al. 2014).

INTRODUCTION

TRADITIONAL TREATMENT OPTIONS FOR SSD
Traditional treatment options for SSD include the CROS system, and more recently osseointegrated and bone conduction hearing devices. These treatment options have the same goal, routing of the signal to the better, contralateral ear.

CROS - Wireless transmission and presentation to the through air conduction. Giardina et al. (2014) reported that overall, the CROS device is ineffective in improving listeners' experience in noise and in regards to localization performance.

BONE CONDUCTION OPTIONS- Comparison of CROS and bone conduction devices indicated superiority on both subjective and objective outcome measures for BC options including: *increased speech perception in noise, moderate improvements in sound localization* and *overall patient satisfaction* (Bishop & Eby, 2010). However Peters et al. (2015) found no benefit with the addition of either treatment option for performance on sound localization tasks. Bishop and Eby (2010) noted that both CROS and BAHA fell short in terms of patient satisfaction and sound localization.

COCHLEAR IMPLANTATION IN SSD-Began in the 2000's as an exploratory treatment option for individuals with SSD with the presence of ipsilateral tinnitus. Research over this short time has demonstrated great success in reduction of tinnitus severity and self-perceived functioning in those individuals (Gartrell et al., 2014; Vlastarakos et al. 2014).

STATEMENT OF PURPOSE

Speech perception in noise and localization are compromised in individuals with SSD. Cochlear implantation was introduced as an experimental treatment option for suppression/abatement of tinnitus. Recently, the focus has shifted to the potential reintroduction of binaural effects, and subsequently, improvements in speech in noise and localization performance through this treatment modality. ***The aim of the present systematic review was to critically assess the current evidence of the efficacy of cochlear implantation as a treatment option for SSD.***

METHODS

A comprehensive review of the literature looking for three primary endpoints: (1) assessment of cochlear implantation for speech comprehension in noise for individuals with SSD (2) assessment of cochlear implantation in sound localization for individuals with SSD (3) assessment of cochlear implantation as a treatment option in unilateral tinnitus. After identification of articles that were appropriate for analysis, full text articles were reviewed to identify individual patients who met inclusion criteria for the present systematic review. Inclusion criteria for individual patients were adults (18+) with unilateral, post lingual deafness with normal to near normal hearing (PTA 0.5,1, 2 & 4 kHz ≤ 30 dB) in the contralateral ear. Data measures post cochlear implantation that were extracted for review included the following: (1) objective test performance for speech in noise measures (2) objective test performance for speech and sound localization (3) scoring on standardized questionnaires (4) subjective tinnitus (5) subjective speech comprehension (6) subjective speech/sound localization.

Assessing Quality of Studies
Assessment of quality of the included studies was adapted from a recent review of the literature conducted by Zon et al. 2014.

RESULTS & DISCUSSION

STUDY	N/Follow-up	Speech Perception in Noise	Localization	SSQ/Subj. outcomes	Tinnitus	Comments
Arndt et al. (2010)	11 adults, 6 month follow-up	**SCI/NNH-(unaided**, CROS, BAHA) **SNH/NCI**-(CROS,BAHA)	Sig. improv. compared to unaided, CROS and BAHA.	Speech-(Unaided, CROS, BAHA)	8 out of 10 partic. w/ pre-op tinnitus rep. improv.	
Erbele et al. (2014)	3 adults, 4-17 month follow-up		Sig. improv. 2 out of 3			Patient 2 and 5 showed sig improv. With the CI when compared to the unaided cond. Pt. 5 also dem. Improv as compared to OHD. NI for Pt. 4
Firszt et al. (2012)	3 adults, 4-17 month follow-up	NI-*No decrement-	Sig. improvement with CI.	P1 & P3>Spatial P1> Speech	3/3 reported sub. tinnitus relief	Psychoacoustic tasks rendered lowed JND's for temporal and spectral complexity with the addition of the CI.
Hansen et al. (2013)	17 adults, 3-12 month follow -up		Sig. improvement with CI			12 month post-op data available for only 6 partic. Overall group data suggests improv. w/CI and trend in improv. over time.
Hassepass et al. (2013)	17 adults, 3-12 month follow-up	**SCI/NNH** **S0/N0**-slight improvement	Sig. improvement	Sig. improvement on all 3 subsections.	Not assessed	Localization improv. noted as compared to unaided, CROS and BAHA conditions. For SCI/NNH-imp.Noted as compared to **unaided**, CROS, BAHA.
Mertens et al. (2013)	15 adults, 12 month follow-up				Sig. reduction on VAS	SRT in noise for the significantly improved in the contra. ear when the CI was activated in 13 of the 15 participants.
Ramos et al. (2012)	4 adults, 6 month follow-up				Sig. improv.	Sig. improvements in all 4 partic. On VAS and THI.
Stelzig et al. (2011)	4 adults, 6 month follow-up	**S0/N0**		VAS-CI acceptance-, integration, ease of listening etc.		Improvements noted in the S0/N0 condition on the FMS test at 15, 5 & 0 dB SNRs. > at 0 dB. Improvements on HSM sentence test noted at 0 and -5 dB, greatest at -5 dB SNR.
Tavora-Vieira et al. (2013)	9 adults, 3 month follow-up	**S0/N0, S0/NNH,SCI/NNH**		Imp. in all 3 subsections	TRQ-7/7 with pre-op tinnitus.	Mean group improvements on crit. SNR for BKB-SIN were 3 dB (S0/N0), 4 dB (S0/NNH) and 5 dB (SCI/NNH).
Tavora-Vieira et al. (2014)*	16 adults*, 6-18 month follow-up			Mean RMS error dem .sig. improvement		*6 partic. were also inc. in the Tavora-Vieira (2013) study. Sig. findings inc. DoD and age at imp. did NOT affect local perf.
Van de Heyning et al. (2008)	11 adults, 1-24 month follow-up				Sig. improv.	Reduced tinnitus loudness via the VAS in all participants 12 months post-op, with the CI-activated, and with it deactivated for more than 1 hour. 3 of the 11 participants reported complete inhibition of the tinnitus after deactivation of the device for at least 12 hours
Vermeire & Van de Heyning (2009)**	10 adults, 12 month follow-up	**SCI/N0**		Sig. Imp. Noted for all three subsections		

LIMITATIONS OF THE RESEARCH ON TREATMENT EFFICACY

- Majority of studies on this topic are of low or moderate levels of evidence.
- No randomized studies and actual numbers of participants in each study remain very low.
- Large degree of inter-study variability in terms of the classification of SSD(varying degrees of hearing in the contralateral ear), duration of deafness, age at implantation, and test conditions, materials and methodology. Differences between test methodology and spatial configurations for SPIN testing may have led to variable results on this outcome measure.
- Follow-up duration post implantation is a limitation for many of the included studies. It is well known that performance with Cis often improves with time and experience, with some research suggesting continued improvements up to 30 months post-implantation.
- Three studies which compared performance with the CI to those of pseudo-binaural forms of intervention, did so with patients who were dissatisfied with the latter forms of intervention. Therefore, subjective outcome measures may reflect their bias towards more conventional treatments.
- Future studies should include larger numbers of participants with control duration of deafness, degree of hearing loss in the contralateral ear and data collection post-implantation.
- Test methods and spatial configurations for assessment of speech in noise performance should be standardized.

SPEECH IN NOISE

- 5 out of the 6 studies reported benefits in speech in noise for ***at least one*** spatial configuration.
- Stelzig et al. (2011) reported significant improvement in the Freiburg monosyllabic word test and HSM sentence test in the **S0/N0** configuration **(binaural summation)**, with greater improvements noted at more challenging signal to noise ratios. Performance in this spatial configuration demonstrated improvement in eight of the nine participants in the Tavora-Vieira et al. (2013) study.
- **Binaural squelch** was assessed through administration of speech in noise testing in the **S0/NCI** spatial configuration. Individual data from the Tavora-Vieira et al. (2013) study demonstrated reduced critical SNRs in five out of nine participants. Two of the four participants in the Stelzig et al. (2011) study demonstrated slight improvements in their SRTs for OLSA sentence testing.
- Overall, objective results from the included studies provide substantial evidence to suggest that cochlear implantation allows for the ***reintroduction of binaural effects*** through electrical stimulation, though it is unclear as to which binaural effects are truly responsible for the improvements in performance.
- The two studies that administered psychoacoustic tasks suggest ***improvements in spectral and temporal resolution*** with use of the CI and possible benefits of the head shadow, as well as other binaural effects.
- Tavora-Vieira et al. (2013) found that these improvements ***were not unique to patients with short durations of deafness***. Benefits in speech perception in noise were demonstrated by patients with long durations of deafness, who lost their hearing post-lingually.
- Subjective improvements of speech perception were measured through administration of the SSQ. In all five studies significant improvements in the speech subsection were noted in the CI-aided condition.

LOCALIZATION

- All 6 studies indicated significantly improved performance with the CI as compared to the monaural condition.
- Arndt et al. (2010) and Hassepass et al. (2013) reported improvements in localization when compared to the BAHA and CROS conditions.
- Tavora-Vieira et al. (2014) found no effect of gender, age at implantation and duration of deafness on localization performance.

TINNITUS SUPPRESSION

- Combined data from all 5 studies demonstrates significant and consistent reductions in tinnitus loudness and distress.
- Mertens et al. (2013) provided data that illustrates how incapacitating tinnitus not only results in psychological distress and perceived handicap, but also adversely effects speech in noise performance in the contralateral ear. CI in SSD can therefore prevent further deterioration of speech in noise performance for SSD patients with ipsilateral tinnitus.
- Van de Heyning et al. (2008) provided critical data that indicates CI is an ***effective long-term treatment option*** for patients with SSD and ipsilateral tinnitus.

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