



Evidence-based study on performance environment for people with and without cochlear implants (CI)

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The primary scope of this study is in finding purely acoustical ways of supporting performers of acoustical music and speech. Field tests with musicians and speech coaches have showed that support is often welcomed even with normal hearing performers [1]. This study extends those tests with hearing and sight-impaired people. When performing with a microphone and a PA system, the monitor loudspeaker has been found as an important asset, but our results point towards other possibilities, as well.

During music-making, the limitations in auditory feedback require some extra effort from the performer, e.g. in optimizing ensemble positions on stage to get a satisfactory soundscape. This is especially poignant and observable with blind Cochlear Implant users [2]. Contemporary CIs have improved speech perception abilities, but they are still challenged with music perception. In a CI, the frequency range and spectral resolution of normal hearing is substituted with 14 -24 channels. One of the writers, the CI user, has found that a felt-brimmed hat enables him to adjust better to the music performance soundscape. The hat acts primarily as an extension of outer ear by giving more selectivity: attenuation to unwanted environmental sounds and enhanced perception of own voice.

One main finding was that an anechoic room was the best suited for music making for one CI user.

1. Introduction

The primary scope of this study is in finding purely acoustical ways of supporting acoustical performers. Previous field tests with musicians have showed that support is often welcomed with normal hearing performers, both speech, singing and instrumental [1]. Goal here is to increase knowledge and to extend evidence on how to design supporting elements to performances. This is done by an experienced performing musician with special sensory needs using cochlear implants (CIs) and with several decades of experience in analytically tackling these problems.

CIs represent the user with many challenges due to the processed audio signal that substitute the normal auditive soundscape with a condensed electro-magnetic stimulation to represent the original soundscape in 14-24 channels to the auditory nerve. The processing techniques vary somewhat according to the CI coding but the differences are not significant with reference to this study.

1.1. Scope

This study partly replicates previous tests [1], now with hearing and sight-impaired people. We study sound localization capabilities with a set of natural signals. The aim is to get basic, hands-on material for further studies in musical performing.

Soundscape is something that only attracts attention when there is something disturbing (noise or irritating echoes, or colourings) in the environment. The normal hearing people can diminish the effects of the disturbing noise or sounds by turning their attention away from it [3]. Attention is a powerful tool when it comes to choosing between different sound sources: you can decide to concentrate to a single instrument in a band or ensemble situation and discard the others. This option is often almost completely unavailable for the hearing impaired people.

Large amount of literature exists about acoustical properties in music performing facilities from the listeners' point-of-observation [10,11], but very little about how small ensembles feel the performing environment and whether it supports or counteracts with their music making and performance.

Early reflections back to the stage can act as acoustical i.e 'unplugged' monitor speakers and help individual singers, speakers and players in balancing their effort. A very important extension to this is how the stage and the hall can help a performing ensemble to hear their mutual balance and timing. These factors are less apparent with performers with long experience, because muscle memory and other features support confidence even in less-than-ideal situations.

A big factor in the stage scenario is the positioning of the performer, especially if the person is depending on the feedback, as is the case with the hearing-impaired, e.g CI users. If for example the players are in a circle formation, the sound from the bass amplifier and drums can overload the CI causing overtoning. Through trial and error it was found that the best position is for the CI user to be in the front, with the bass amplifier positioned directly behind as far away as possible and the drummer should be to the left side of the CI user as the CI user's best ear is on the right side. At the same time the CI user adjusts the CIs through the remote control reducing the volume and the sensitivity level of the left CI and simultaneously increasing the volume and the sensitivity levels on the right side CI so that the distorting noises are not picked up from the left side and is therefore able to hear own singing voice clearer.

1.2. Cochlear Implant intro

Contemporary CIs have improved speech perception abilities, but they are still challenged with music perception. Cochlear implants (CIs) are used when the individual's hearing loss cannot be helped with traditional hearing aids. CI surpasses the human cochlea and acoustical hearing, and transmits the surrounding sounds to the auditory nerve by electric stimulation, e.g. [4]. Speech perception abilities in contemporary CIs are quite adequate in a quiet environment, but speech in noise still presents a challenge for the CI user [5]. This can be alleviated somewhat by bilateral CI use. Contemporary CIs compress the frequency range and spectral resolution of normal hearing into 14-24 channels, depending on the brand in question. This presents challenges in voice quality perception as well as music perception, as both voice quality and music are used to express emotions [6]. The perception of emotional quality in speech with CIs is one of the contemporary areas of interest in speech science [7]. Music is by far one of the most complex auditory signals present in the soundscape (for an extensive report on CI constraints to music perception, please see [8]).

CIs represent the user with many challenges due to the processed audio signal that substitute the normal auditive soundscape with a condensed electro-magnetic stimulation to represent the soundscape. CI uses bandpass filtering to separate between channel information, so the CI processor separates the holistic acoustic input into several frequency components. The tonotopical setting in the cochlea stimulation resembles the normal situation in that the higher the frequency relayed the more apical stimulation pattern it is, though in comparison to normal 35000 inner hair cells the information is provided by only 14-24 stimulation electrodes. Furthermore, the signal is preprocessed to emphasize speech cues [8].

During a performance scenario, our CI user is wearing two CIs with a remote controller to adjust the volume and microphone sensitivity plus four individual programs, one of the programs being for use in performance. One key problem, when playing with other ensemble members, such as bass guitar, drums and electric guitar, is the extra amplified sound levels that are produced within the environment. The CI user, who sings and plays the guitar, has to adjust the CIs to avoid distortion and overtoning from other instruments. For example if the CI user is playing a specific chord on the guitar which is then replicated on the bass guitar, the loudness of the sound can be over amplified causing the CI user to go out of pitch during singing [9]. This is because the CI has not been adjusted correctly to deal with all the different acoustic sounds present in the environment.

1.3. Sound localization

Soundscape is something that only attracts attention when there is a disturbing noise in the environment, be it traffic noise, air conditioning in an office or an unwanted reflection of a sound or sounds in a concert hall [10]. The normal hearing people can diminish the effects of the disturbing noise or sounds by turning their attention away from it [3]. The ability to choose to listen to one particular voice in a babbling crowd is called a cocktail party effect [11]. These options are unavailable to the hearing impaired people.

Sound localization experiment was done for experimenting how well an individual with bilateral CIs can determine the location of a random sound source. Sound localization has not been in focus in the hearing rehabilitation but only recently when CIs have been operated bilaterally, that is to both ears. People need two distinct sound input sources to be able to map the sound scape for location analysis. This is basically done by subtracting the time lapse between inputs.

Sound localization can be enhanced by turning one's head to increase the time or phase difference between the inputs to each ear [12, 13]. Most of the CIs are operated only to one ear and sometimes the hearing aid is not well balanced, so sound localization is not as accurate as it might be with bilateral implantation. There are also cases where there is only one hearing aid or implant in use. Sound localization then becomes impossible if there is only one sound source available.

2. Methods

1.1. Test signals

To create non-artificial musical tones with no tonal scale feeling, a piston whistle was recorded beforehand in the anechoic chamber. The frequency of the tone beeps was determined by the random positioning of the whistle piston. The randomness was needed to avoid learning by the (musically very experienced) subjects.

Each singular beep tone in the recording was then normalized to its highest sound pressure level and extra noises removed from the recording with Audacity software. The signals had their original level variations and some tonal bending. The duration of the test series was about three minutes. Total number of test signals was 40. The inter-stimulus interval (ISI) varied between 490 and 2390 ms within the test session.

1.2. Directional hearing test

Each subject (N=2) sat blindfolded (to avoid visual cues of location) on a stool in the middle of the anechoic chamber. In this test set two different hats were used to investigate how acoustic close-up reflectors (in this case hat brim and cap shade) influence sound localization ability by reflecting or deflecting the incoming sound waves. The same test set was done in 10 different scenarios.

The researcher stood behind the subject with a short fishing rod carrying a loudspeaker connected by Bluetooth to signal source (mobile phone). The loudspeaker was moved to eight directions on a horizontal 360 degree plane and

three vertical levels at approximately the same distance yet randomly around the subject. The task of the subjects was to point to the sound source.



Figure 1. The direction-pointing test equipments: Bluetooth loudspeaker in a pouch and bright-coloured flag on tip of a short fishing rod, video camera and blinding eye glasses.

The series was repeated ten times:

- 1) no hat
- 2) felt brim hat, no tilt
- 3-6) felt brim hat tilted left, right, front, back
- 7-10) baseball cap pointed front, left, right, back

Analyses were made later visually from a video recording and the number of clearly correct and the number of clearly not correct items were calculated. The researcher used two hand-held counters to add clearly matching and clearly non-matching items to two counter devices. Unclear items were not counted.

The CI test subject noted "The sound was directed from all angles, below, above and horizontal plane from me. This I didn't realize until after the session as most of the sounds appeared to be coming from the horizontal level. One could compare this to the hospital's localization of sound test, but the difference is in place of a horizontal plane up to 180 degrees this included up, down and behind scenarios." (CI test subject, personal information on 10th April, 2014)

3. Results

In these 3D results, errors in vertical direction are counted as errors even when lateral result was correct. The 3D results are listed in table 1. Because of a possible misinterpretation of the test explanation the results were re-interpreted with a new paradigm where errors in vertical dimension were not counted as errors when lateral result was correct. These new results are referred as 2D results (Table 2).

The CI user also made larger proportion of unclear direction indications than NHI, maybe because of a longer decision time needed. This was, however, not without exceptions. The test was quite demanding and some distinct changes in attention were observable. Below is a table of tokens left undefined during the analysis from the video (Table 3), providing us with confidentiality score to be able to judge the best performances in sound localization.

Table 1. Number of correct and not correct pointing results when vertical plane errors are included

CI User's results				Normal hearing results			
	correct	not	difference		correct	not	difference
No hat	14	19	5- ←weakest	No hat	29	7	22+ ← good
Hat, no tilt	17	19	2-	Hat, no tilt	21	12	9+
Tilt left	21	18	3+	Tilt left	21	16	5+ ← weakest
Tilt right	18	15	3+	Tilt right	26	8	18+
Tilt front	21	13	8+ ←BEST	Tilt front	31	5	26+ ← BEST
Tilt back	17	21	4-	Tilt back	28	7	21+ ← good
Cap front	20	13	7+ ← good	Cap front	32	7	25+ ← BEST
Cap left	21	13	8+ ← BEST	Cap left	26	9	15+
Cap right	17	19	2-	Cap right	22	14	8+
Cap rear	15	19	4-	Cap rear	27	10	17+

Table 2. Number of correct and not correct pointing results when vertical plane errors are allowed

CI User's results				Normal hearing results			
	correct	not	difference		correct	not	difference
No hat	20	14	6+	No hat	32	7	25+
Hat, no tilt	29	10	19+ ← BEST	Hat, no tilt	33	5	28+
Tilt left	28	11	17+ ← BEST	Tilt left	25	11	14+
Tilt right	24	14	10+	Tilt right	31	3	28+
Tilt front	22	14	8+	Tilt front	36	0	36+ ← BEST
Tilt back	22	16	6+	Tilt back	30	3	27+
Cap front	22	7	15+	Cap front	30	3	27+
Cap left	24	9	15+ ← good	Cap left	35	1	34+ ← good
Cap right	25	11	14+	Cap right	27	9	18+
Cap rear	25	14	11+	Cap rear	29	4	25+

Table 3. Number of unclear pointings found during analysis of the video recording

	CI user 2D	NHI 2D	CI user 3D	NHI 3D
No hat	6	1	7	4
Hat, no tilt	1	2	4	7
Tilt left	1	4	1	3
Tilt right	2	6	1	3
Tilt front	8	4	6	4
Tilt back	6	7	2	5
Cap front	11	7	7	1
Cap left	7	4	6	5
Cap right	4	4	4	4
Cap rear	1	7	6	3

4. Discussion

The felt-brimmed hat with a front tilt yielded the best results in both test subjects. This positioning of the hat is the same used by a CI user when there is a need for deflecting unwanted sounds e.g. in an ensemble scenario. There was a discrepancy of the test results in that the first test scenario (no hat) for the normal hearing subject yielded good results, but for the CI user that particular scenario yielded the weakest localization results. This might reflect the fact that a CI user cannot use external ear in sound propagation to the inner ear but needs an extra reflecting surface on top of the ear lobes. One of the most interesting results is that the resulted in both 2D and 3D scenarios for the hat tilt front was exactly the same for the CI user. In both test subjects the errors made in vertical axis were in majority, however, the CI user was unsure whether the sound source could be also deviant from horizontal plane and the fact of 360 degrees and below and above scenarios. This was re-asserted and re-confirmed for the CI user after a prompt before the two last test series. There was a need for assertion and confirmation of the possible sound source locations despite the initial procedure explanation with mapping of possible sound source locations. This results in a need for re-analysis of the 3D results where the errors in vertical axis are ignored for both subjects. And again, that re-analysis might yield new and different percentages in error rates both within and between subjects.

The change into the 2D results yielded improvements on the results for both of the subjects. The improvements were similar for both. The best scenarios changed somewhat as for the CI user the best scenarios were the hat with no tilt and the front tilt. The latter was the same as in the 3D results and also the one previously used by the CI user. The worst scenario for the CI user was the same (no hat) despite the change in the result template. For the normal hearing subject the best scenario changed somewhat as whereas the hat with no tilt was one of the best yet again, the cap left scenario was one of the best too.

The next stage was to look at the undefined tokens per scenario as to confirm if the good results are explicable, that is if in the good test result scenarios also the undefined tokens are few. In some cases good results are obscured somewhat with the high undefined token count in the test scenario, but most often the best results coincide with low undefined token count.

5. Conclusions

Results showed that the extra reflections from the hat brim were needed for the CI user to be more accurate on sound localization. The same conclusion was suggested a priori the experiment as the CI user was used to using a hat in a scenario where there was a need to deflect unwanted sounds as well as reflect sounds the user wanted to monitor more closely. The hat also improved sound localization for the normal hearing subject, so acoustic reflectors can be used to design a more appropriate soundscape whenever there is a disturbance, be it for an unwanted noise or for an artefact due to hearing aids or CIs.

Next day, the CI test person wrote an email to the researcher about what he had experienced as a music performer in the anechoic rooms (abridged):

"In the afternoon there was an opportunity for me to try out singing and playing the guitar in the other anechoic chamber alone. I was not using the hat in this situation and was just playing away my songs plus some old ones I haven't played for a long time.

To my amazement and for the first time, I realized I was able to hear myself in a totally different way. In other words, to keep perfect pitch and to increase my vocal range for the first time. For example, when singing 'Try to Remember', I have always had problems due to the higher key and the holding of notes. This for me was a quite an emotional moment realizing everything went so smoothly. Similarly when I sang

other songs from my repertory I felt I had imperfections in some places, but these were all easy to correct immediately and I was truly astonished in realizing this. The only explanation I can give is that it happened because all the reverberations and other sound sources of the normal environment were absent.

This also made me realize this is the sort of sound I would need to hear either through some filtering system or self-monitoring device musicians use when on stage. This would be to enhance my own performance both as a solo or with a band ensemble.

When using the hat I noticed there was a better amplification of my own voice. I was even able to get loudness and softness right which has been difficult."

These subjectively found and quite unique results were an unexpected finding to everybody and seem to point to totally new goals when designing accessibility to hearing-impaired persons towards music-making and inclusive musicking of people with special needs.

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