



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 the performers. Field tests with musicians have showed that support is often welcomed even with normal hearing performers [1]. This study replicates 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.

During music-making, the limitations in auditory feedback require some extra effort from the performer, e.g. position in the room to get a satisfactory soundscape. This is especially poignant and observable with 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 CI user has found that a felt-brimmed hat enables him to perceive his own voice clearer. 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. The concept of signal-to-noise ratio must in these cases be extended to S/M/N-ratio, including the Monitoring of own sound.

Methods of the study include tests in an anechoic chamber with and without added early reflection (20-80ms) employing quantitative measurements of musical synchronization (pitch and attack) in simulated ensemble situations.

1. Introduction

The primary scope of this study is in finding purely acoustical ways of supporting the performers. Previous field tests with musicians have showed that support is often welcomed with normal hearing performers [1]. Goal here is to increase knowledge and to gather evidence on how to design support elements for performers with special acoustic support needs, that is performers using cochlear implants (CIs).

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 wrt. this study.

1.1. Scope

This study replicates previous 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. During music-making, the limitations in auditory feedback require some extra effort from the performer, e.g. position in the room to get a satisfactory soundscape.

Soundscape is something that only attracts attention when there is a disturbing noise 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]. This option is not available for the hearing impaired people. Attention is a strong and 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.

Qqqq – Heikki: Room acoustics and sound reverbation (Heikki)

1.2. CI 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 emphasise speech cues [8].

1.3. CI user perspective

During a performance scenario the CI user is wearing two CIs with a remote controller to adjust the volume and microphone sensitivity plus four individual programmes, one of the programmes 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 overtone 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.

Another factor in the scenario is the positioning of the CI user. 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 his CIs through the remote control reducing the volume and the sensitivity level of his left CI and simultaneously increasing the volume and the sensitivity levels on the right side CI so that he is not picking up distorting sounds from the left side and is therefore able to hear his own singing voice clearer.

1.4. Sound localisation

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 localisation experiment was done for experimenting how well an individual with bilateral CIs can determine the location of a random sound source. Sound localisation 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 localisation 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 localisation 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 localisation then becomes impossible if there is only one sound source available.

2. Methods

2.1. 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.

The same signal file was used for both directionality tests and pitch tracking tests.

2.2. Directional hearing test

Each subject sat blindfolded (to avoid visual cues of location) on a stool in the middle of the anechoic chamber. Size of chamber here. In this testset different masks were used to investigate how acoustic reflectors (in this case hat brim and cap shade) influence sound localisation ability by reflecting or deflecting the incoming sound waves. The same testset 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.

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.

2.3. CI user perspective

“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.

| CII | + | - | DIFF | |
|--------------|----|----|------|--------------|
| No hat | 14 | 19 | 5- | <--- weakest |
| Hat, no tilt | 17 | 19 | 2- | |
| Tilt left | 21 | 18 | 3+ | |
| Tilt right | 18 | 15 | 3+ | |
| Tilt front | 21 | 13 | 8+ | <--- BEST |
| Tilt back | 17 | 21 | 4- | |
| Cap front | 20 | 13 | 7+ | <--- good |
| Cap left | 21 | 13 | 8+ | <--- BEST |
| Cap right | 17 | 19 | 2- | |
| Cap rear | 15 | 19 | 4- | |

| NHI | + | - | DIFF | |
|--------------|----|----|------|--------------|
| No hat | 29 | 7 | 22+ | <--- good |
| Hat, no tilt | 21 | 12 | 9+ | |
| Tilt left | 21 | 16 | 5+ | <--- weakest |
| Tilt right | 26 | 8 | 18+ | |
| Tilt front | 31 | 5 | 26+ | <--- BEST |
| Tilt back | 28 | 7 | 21+ | <--- good |
| Cap front | 32 | 7 | 25+ | <--- BEST |
| Cap left | 26 | 9 | 15+ | |
| Cap right | 22 | 14 | 8+ | |
| Cap rear | 27 | 10 | 17+ | |

In these "2D" results, errors in vertical direction are not counted as errors when lateral result was correct.

| CII | + | - | DIFF | |
|--------------|----|----|------|---------------|
| No hat | 20 | 14 | 6+ | |
| Hat, no tilt | 29 | 10 | 19+ | <--- Best |
| Tilt left | | 28 | 11 | 17+ <--- best |
| Tilt right | | 24 | 14 | 10+ |
| Tilt front | | 22 | 14 | 8+ |
| Tilt back | | 22 | 16 | 6+ |
| Cap front | | 22 | 7 | 15+ |
| Cap left | 24 | 9 | 15+ | |
| Cap right | | 25 | 11 | 14+ |
| Cap rear | 25 | 14 | 11+ | |

| NHI | + | - | DIFF | |
|--------------|----|----|------|---------------|
| No hat | 32 | 7 | 25+ | |
| Hat, no tilt | 33 | 5 | 28+ | |
| Tilt left | | 25 | 11 | 14+ |
| Tilt right | | 31 | 3 | 28+ |
| Tilt front | | 36 | 0 | 36+ <--- Best |
| Tilt back | | 30 | 3 | 27+ |
| Cap front | | 30 | 3 | 27+ |
| Cap left | 35 | 1 | 34+ | |
| Cap right | | 27 | 9 | 18+ |
| Cap rear | 29 | 4 | 25+ | |

Undefined tokens by session

CIuser 2D - NH 2D

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-----
no hat 6 - 1
hat no tilt 1 - 2
tilt l 1 - 4
tilt r 2 - 6
tilt f 8 - 4
tilt b 6 - 7
cap f 11 - 7
cap l 7 - 4
cap r 4 - 4
cap b 1 - 7
-----

```

CIuser3D - NH 3D

```
-----  
no hat 7 - 4  
hat no tilt 4 - 7  
tilt l 1 - 3  
tilt r 7 - 6  
tilt f 6 - 4  
tilt b 2 - 5  
cap f 7 - 1  
cap l 6 - 5  
cap r 4 - 4  
cap b 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 localisation 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 result 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 localisation. 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 localisation 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.

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